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ON THE

MANUFACTURE OF IRON.

To
A. Wilkins Esq
Concerto
with the regards of
W. W. Anderson
March 16th 1878.

REPORT

ON THE

MANUFACTURE OF IRON;

ADDRESSED TO THE

GOVERNOR OF MARYLAND:

BY

J. H. ALEXANDER,

TOPOGRAPHICAL ENGINEER OF THE STATE.

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HIS EXCELLENCY,

WILLIAM GRASON,

GOVERNOR OF MARYLAND:

I HAVE the honor to lay before your Excellency, herewith, a Report on the Manufacture of Iron, with reference particularly to its extent and amount in Maryland.

What has been here done, will much diminish the difficulty and labor of collecting, annually hereafter, such statistical facts as will keep pace with the progress of a branch of industry, which is continually increasing in importance to the State.

I beg your Excellency to accept the assurances of my profound respect.

J. H. ALEXANDER.

ANNAPOLIS, 13 *March*, 1840.

INTRODUCTION.

The following Report is the fruit of a careful examination of several establishments for manufacturing Iron in Great Britain, performed during the summer and autumn of the past year, and of similar inquiries extensively made from establishments of the same kind in our own State.

Its design was to exhibit the results which had been already attained in this department of productive industry, among ourselves; and also by the suggestion of advantageous and improved methods, employed elsewhere, but unknown or little used here, to contribute in some degree to its farther advancement.

The work is divided into four Chapters: of which the first contains a sketch of the history of this manufacture through its successive periods. The question of its antiquity (which has been by all preceding writers *assumed*, on the one or the

other side,) has not been discussed, farther than to present the testimonies of the principal authorities that bear upon the subject. To do this, I have of course been obliged to refer to the ancient classical writers, and sometimes to quote their own words; but, I hope, it will not be found that I have been led away into any minuteness of verbal criticism or affectation of literary research, inconsistent with the practical nature of the matter. The portion of this chapter which relates to the modern history of the manufacture, is merely a chronological arrangement of its progressive epochs, according to the best authorities; and the part relating to Maryland is supposed to be interesting, as shewing the very important relations which our State has already, in this regard, held to the manufacturing interests of Great Britain. I have been careful to append in notes, detailed references to the authorities which I have consulted: from the farther examination of which, any one, so disposed, may pursue the subject into more details than would have been suitable in the present sketch.

The second Chapter contains a view of the geographical position and occurrence of the different ores of Iron, according to their respective uses and applicability, in a metallurgic sense, for manufacturing purposes. The present geological survey of Maryland enables me to give more accuracy and general interest to this view, (so far as our own territory is concerned,) than could otherwise have been attained or expected.

The third Chapter is devoted to miscellaneous particulars, (yet arranged with as much order and precision as could be used,) touching the materials and methods, which are applied in the different stages of manufacture. I have taken some trouble to

exhibit copious analyses of the ores, coals, &c. which enter into the primitive processes; and in this regard it may be looked upon as the depository of some valuable information, hitherto much scattered or not accessible. It was my purpose to have presented these particulars, as they relate in full to the preparation of bar-iron, as well as the manufacture of crude or pig-iron; but I found, that to do this, would expand the size of the Report beyond either the present convenience of the writer, or perhaps the taste and patience of its readers. That portion is therefore reserved for another occasion.

I look upon the publication of this part of the Report, as likely to be attended with desirable results in two ways: 1° the great facilities which exist for a cheap manufacture with mineral coal in the western part of the State, will be encouraged and advanced by more knowledge of the successful methods, which are universally applied in the use of the same fuel, in Great Britain: and 2° the English manufactories, from the exhibition of favorable results in this country from another fuel, may possibly be induced to employ the charcoal of wood, (which is in sufficient plenty to admit of much more extensive appliance than is now allowed to it,) in several processes; whereby we may expect the production of a better, and proportionably a cheaper article.

On the apparatus, and its modifications, for the hot-blast, I have not said as much as it would otherwise deserve, because an English translation has not very long since been made of the elaborate enquiry of a French Commission (in 1834, deputed to England) with regard to this very subject: and it has been rather my aim to furnish new and well verified facts, than to compile merely a resumé of those, which had been observed, commented on, or published in such form as to be of easy access, before.

The use of anthracite as the fuel for blast-furnaces, (which has long been of much interest to the proprietors of the fields of that sort of coal in Pennsylvania, and is lately becoming more so, on account of the reputed successes with a similar combustible at the Yniscedwin Works in S. Wales,) has not been discussed, because of its want of connection with the processes that are or can be employed in Maryland, where no anthracite occurs. It is presumed, that the principles which are laid down in the course of the Report, are equally applicable to all kinds of fuel, according to their respective constitutions; and that with an anthracite not presenting too much earthy matter in combination, nor having the property of decrepitating into small fragments upon the application of heat, both of which are frequent occurrences, there would be no obstacle, with a suitable supply of air, in manufacturing hot-blast iron. Whether an economy, as great as that affirmed by Mr. Crane, will occur in the general average employment of this fuel, is a matter that cannot yet be judged of: and the quality of the iron so made, except inasmuch as it is reasonable to suppose the metal will partake of all the qualities, favorable and unfavorable, of hot-blast iron, is equally now to be left indeterminate.

The fourth Chapter treats of the most important chemical phenomena which are observable in furnaces, and attempts to explain them upon correct and well recognized chemical principles. As far as theory admits of practical application, it would go to diminish much of the irregularities and make up for the deficient production of many establishments, particularly in our own country. Almost the first step that was taken on this subject in England, (otherwise than the occasional references of scientific chemists,) was in 1819, by a man who deserves to be considered,

in many regards, an extraordinary person. Samuel Rogers, (the name of this person,) a working-hand about one of the establishments in Monmouthshire, had yet by some means acquired a very judicious comprehension of the aim and application of the science of chemistry; and several of the remarkable discoveries of the last fifteen years in this manufacture, are to be found, either in germ or more distinctly brought out, in certain letters, which during the year mentioned, he wrote and proposed to publish. There was reason to suppose that the effect of his views, if adopted, would have tended to equalize the proportionate products of establishments of different sizes, and possessing different natural advantages: but the interest of the large and favourably situated manufactories was not to encourage this equalization, or, as they thought it, rivalry; and, by temptations of whatever kind, Rogers was induced to give no more than his first three letters to the public. But a few copies of the work, as he had prepared it, still exist in manuscript; and one of these is now in my possession. Upon a careful perusal, I cannot but think that the Iron-masters over-rated the influence which the entire publication would have had; and Rogers was perhaps acute enough to come to the same conclusion. However, it would have been unjust in any treatment of the same subject, to have withheld the honorable mention of himself and his work, which I have thought proper here to make.

Connected with the objects of this chapter, is the assemblage of principles upon which may be based a classification of the different kinds of crude iron that are manufactured. I have pointed out all the well recognized distinctions that have led to the formation of existing classes, and, as far as could be, have endeavoured to shew how these and others (not perhaps so well known) may lead to a greater generalization. As an adjunct in

this purpose, I have alluded to some new researches, which I had made, before and during the preparation of this Report, upon the mechanical structure of crude iron, manifesting itself under a strong microscope. So far as I am aware, the examinations of this sort hitherto, have been, either, upon iron which was under chemical treatment, or, upon specimens fractured under loads, with the view of ascertaining the directions of the strains which had been operative: but neither case seems to have extended itself to embrace the principles or features upon which a new classification could be founded, or the old divisions verified.

The researches to which I have alluded, were made upon the assumption that solid bodies generally, in cooling from a state of fusion, tend to take a regular crystalline form, peculiar to each one respectively; and that in the case of a compound resulting from the union of different substances in the same mass, the crystalline form, after fusion, varies according to the proportions of the several substances, and the degree of heat to which they have been submitted; so that the mechanical properties of such a compound will be manifested, in great measure, by the modifications of its mechanical structure. In the case of crude iron, which is a compound of the nature mentioned, it was expected that the peculiarities of structure would lead to a determination of the proportions of the combined impurities, of the measure of the imponderable agents, (heat, electro-magnetism, etc.) which had been active, of the nature of its mechanical accidents, (cohesion, stiffness, elasticity, etc.) and thus of the greater or less applicability of the same or different specimens, to the several practical purposes for which this metal is every day used. The interest attached to determinations of this kind, both among scientific and practical men, is well recognized.

All the examinations which I have hitherto made, have been of an analytic character: it would be obviously premature to make deductions from them, before the other division (the synthetic experiments upon pure iron exposed to uniform heat in association with different substances) is complete. This is a labor yet to be performed; and I have therefore in this chapter made no further use of the results which I have obtained, than to refer occasionally to the different crystalline forms, which have exhibited themselves in specimens that have come under my inspection, and to point to their connection with the general classification that I have indicated.

The part contributed by the blast towards the formation of crude iron, is of such importance that I have thought it necessary to be somewhat full and particular on this subject; and I have aimed, by the presentation of a new and carefully constructed Table, to furnish means of satisfying several questions of interest in this regard, which could only be answered otherwise after a long calculation.

In relation to the relative strength, and several other mechanical properties, of crude iron manufactured with hot-blast, I have taken pains to collect and exhibit in a series of Tables, the final results of the latest and best experiments which have been made for the determination of this disputed point. In view of the precautions employed, and the fullness of preparation and detail allowed, in these experiments, I think the results I have exhibited may be considered as bringing the question now within narrow limits.

Finally, I have mentioned the several processes which have been devised in Europe for economizing the great proportion of heat which is lost in the ordinary construction of furnaces, both there and here; in the hope that the information may thus

command the attention of those persons to whom it will be very serviceable, and out of whose view it might otherwise have remained. One of these processes, in particular, has been adopted in this State very generally, and to good purpose. There is reason to believe, that the others, properly understood and executed, would be attended with not less beneficial consequences.

The Appendix contains certain particulars, of interest in a statistical regard, and in illustration of points which had to be mentioned with less detail in the body of the Report.

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REPORT

ON THE

MANUFACTURE OF IRON.

CHAPTER I.

Sec. 1. *Ancient History of the Manufacture of Iron.*

The traces of reference to the Manufacture of Iron, in the history of times anterior to our era, are so dim, as with some persons to have justified the opinion that it was almost or entirely unknown. Without attempting to discuss the grounds of this opinion, which involves questions of literal criticism out of place here, it will be sufficient for the purposes of this chapter, to collect and exhibit such ancient Testimonies as relate to the subject; leaving the reader to determine after perusal, whether the terms which we translate *Iron* or *Steel*, are to be considered as really signifying these metals, and to estimate the probabilities that a Material and Manufacture so im-

portant, found too as it is now among nations, who are certainly not to be considered civilized in the modern acceptation, would have been for so many ages in abeyance.

In the oldest book that we possess, the Sacred Writings of the Jews, this metal and the uses of it are frequently mentioned: and its invention is attributed at a very early date, (about six hundred years after the Creation of man) to Tubal-Cain, the seventh in descent from Adam, (Gen. iv. 22.)[1] The Books of Moses, the latest of which is supposed to have been written 1451 B. C. mention also many times elsewhere the metal iron. In the book of Numbers, (xxxi. 22,) is an enumeration of six metals,—Gold, silver, brass, *iron*, tin and lead,—as being a part of the spoils of the Midianites.

In the Book of Job, (xxviii. 2,) which in all probability ante-dates any other writings of those scriptures, it is specially affirmed that iron is extracted from an earth or *Ore*.

The precaution of the Philistines in prohibiting any 'smith in Israel,' is noted in the first book of Samuel, (xiii. 20,) the date of which is probably 1050 B. C. and it may be remarked that the same word is used in this passage and translated *sharpen*, as was before by Moses applied to Tubal-Cain:

[1] Hassenfratz makes the meaning of Tubal-Cain: *celui qui fait des scories de Fer*. He dates Tubal 1057, A. M. But this is on the reading of the LXX.

hence it may be inferred that in the lands of the Philistines, there were persons capable of working through all the processes of Iron-making. In less than eighty years afterwards, the magnificent preparations of David, for the erection of the first temple, included 'cunning workmen to work *iron*,' and mentions particularly the 'iron for *nails* in the doors of the gates and for the joinings;' which metal it is also said was in such abundance, that no account had been thought necessary to be submitted to the King, of it, as of the more precious metals.

The extent to which this metal was used, was no doubt much more limited than at present; as also the modes of its application. Dr. Lowth concludes from a passage in another of the Jewish scriptures, the prophetic writings of Amos, (vi. 12,) that the *shoeing of horses* was unknown at that time; about 790 B. C. I confess that I do not coincide in the conclusion, although it is very likely, in regard to another passage that he quotes (Judges, v. 22,) that at that earlier date, (about 1300 B. C.) the shoeing of horses with iron was unknown; especially as within the recollection of many persons, the practice was by no means of universal adoption in our own country. Indeed, Beckmann dates their introduction into England only at the period of the Norman conquest; when it is known the city of Northampton was given as a fief, whose tenure was the shoeing of the Conqueror's horses. The same

writer also derives the title of the family of lord Ferrers, (whose coat of arms still bears six horse-shoes) from the circumstance of the first who bore the name being the superintendent of the *Ferriers* or Farriers; the etymology of whose trade-name is from the iron (in Latin *ferrum*) they made use of.

To return, however, to the Jewish writers: the prophet Isaiah, about 700 years B. C. mentions the uses of this metal in several places. In particular a passage, (xliv. 12,) has been thought, (though I do not concur entirely in the inference,) to imply the converting process of *Steel*, or at least the hardening of Iron and quenching of it in water, as called by professor Tychsen. In regard to this passage, I shall only introduce here the remarks of the author just mentioned, from his annotation in Beckmann; because they also serve to carry us on in our chronological review of the ancient Hebrew Writers. 'It may,' he says, 'be translated otherwise,' i. e. than as referring to steel, 'but it certainly alludes to the formation of an image of metal. The words in chap. liv. 16, are still more general. Iron *(barzel)* often occurs, and in some passages *steel* may be understood under this name. For example, in Ezekiel, (xxvii. 19,) *ferrum fabrefactum;* or according to Michaelis and others, sabre-blades from Usal, (Sanaa in Yemen.) A pretty clear indication of steel is given in Jeremiah, (xv. 12.): *iron from the north*, which is described there as the hardest. To the north of

Judea was situate[2] Chalybia, the ancient country of steel. It appears that the Jews had no particular name for steel, which theyperhaps comprehended under the term *barzel*, or distinguished only by the epithet *northern;* especially as the later Jews have for it no other name than *istoma;* which, however, is nothing else than the Greek στόμωμα, stomōma, and signifies rather steeling or *hardening.*'

I will only remark on the passage of Jeremiah, that a slight error has crept into our English version; and the word which is rendered *steel*, is in Hebrew the same which elsewhere is used to signify *brass.* Luther, Diodati, and the Clementine Vulgate have all translated it *brass.*

From Ezekiel (who wrote 574 B. C. and about 14 years later than Jeremiah,) I shall quote a single phrase in addition to that already adduced. The prophet says (xxii. 20,) 'they gather—iron—into the midst of the furnace to blow the fire upon it, to melt it.' This comes nearer the idea of a blast-furnace for reducing iron than any other expression I have yet met with in those writings. It is probable that it would be such a furnace or foot-blast, as we are told are used by the Cingalese; about which Dr. Davy has given us an account, and a mention and drawing of which Mr. Hebert's Encyclopædia presents under the article *Iron.*

[2] There has been some confusion as to the position of this country. D'Anville places it in a part of ancient Pontus; Justin, the abbreviator of Trogus, states it to have been in Spain. The subject will be taken up hereafter.

The latest Jewish writer to whom I shall refer is the prophet Daniel, who may be placed about 535 B. C. By every other author the same word before mentioned (*barzel*) is uniformly used to signify iron: in his writings he uses the words *perzel* and *perzela*. Although the lexicographers derive these words from different roots, I apprehend the change from one labial to another (a little more aspirated) is not greater than could have been expected to arise in a removal from the low-country of Judea to a long residence among the mountains of Khusistan. It is very possible that from these words may have been taken the Latin *ferrum*, having the same signification.

The other nations of antiquity coeval with the writers whom I have quoted, the Ethiopians, Egyptians, Assyrians, etc. have left no accessible records to be consulted on this subject. All that can be known of them is to be found in the ancient literature of Greece and Rome, and especially the former. I shall pursue the same course, as with the Jewish writers, of giving the Testimonies of several authors in the order of their respective dates.

Herodotus, about 445 B. C. and a century later than the prophet Daniel, in speaking of Sethos, (Euterpe c. 141,) an Egyptian king, that reigned about 745 B. C., calls him a priest of Vulcan or Hephæstus, who is generally considered in all my-

thologies the representative of the Inventive Spirit in the manufacture of Iron. In another place (Clio, c. 25) he speaks of a curiously inlaid saucer or vase of iron presented by the Lydian Alyattes, the father of Crœsus the Rich, about 600 years B. C.; and its manufacture is attributed to one Glaucus, of Chios. The same vase is mentioned and a minute account given of it by a later writer, Pausanias, who flourished about 170 years after our era: and the discovery of welding iron is likewise affirmed to belong to the same Glaucus.[3] Herodotus also elsewhere (Melpom. c. 62,) speaks of a sword, worshipped from the remotest antiquity by the Scythians. Mr. Beloe and Mr. Gibbon, both call it an *iron* sword or cimetar upon the authority of the historian; though I do not find that in that place he expressly affirms it to be *iron*.

Diodore of Sicily, a Greek writer, flourishing about 45 B. C. has treated of this same subject—the antiquity of the arts among the Oriental nations. He affirms it (Lib. i. c. 15) to be the Egyptian tradition, that Isis and Osiris, the children of Saturn and Rhea, who reigned in very remote times, perhaps 1830 B. C., were the first patrons of Metallurgy.

The same tradition, however, ascribes its actual invention to Hephæstus or Vulcan, a king who preceded Osiris; and who, as said before, bearing the same name and offices in every mythology, may

[3] Paus. Phocic. c. xvi.

well be supposed to have been identical with the Tubal-Cain of the Jewish scriptures.[4]

In descending to periods somewhat later than these, and referring to the Greek writers for the traditions of their own country, they will be found to mount to a very high antiquity in the date of this Invention. Sophocles, nearly the co-temporary of Herodotus, is quoted by Strabo as affirming that the Dactyli, a family who lived upon Mount Ida in Crete, were the first discoverers of the art of smelting Iron.[5] The same thing is averred by Diodore of Sicily, (lib. v. c. 64,) and the probable date is assigned by chronologists of 1400 years B. C. when it occurred.

Much confusion exists with regard to these Dactyli:—some making them to be the nurses of Jupiter, when he was hidden by his mother to keep him from the barbarity of his father Saturn;—others, priests of Cybele, or Rhea, or the Earth, at a period long subsequent to the birth of Jove. Also they are placed sometimes upon Mount Ida, in Crete, as already mentioned;—sometimes in the Creto-Idæan district of Arcadia in the present Morea;—and sometimes in Phrygia. So their number even is variously stated. Pausanias who names them (lib. vii. 4,) makes but *five*—others make them *ten;* and both from the number of fingers (in Greek *dactylos*) on one or both hands. They are called

[4] Calmet. ad voc. [5] Strab. x. c. 3.

twelve by others—and are even magnified into one hundred and three hundred. Mr. Faber has however discussed this, which has not much to do with the present subject, in his dissertation on the Mysteries of the Cabiri.

A much later author, Lucan, who died 65 years after our era, refers in his Pharsalia (l. vi. 398, etc.) to the old tradition of Ithonus, the son of Deucalion, as the first worker in Iron. This is subsequent of course to the Deucalionic deluge, which may be taken at 1500 B. C.; but would date somewhat earlier than the discovery of the Dactyli just now mentioned. The two stories are not necessarily inconsistent: the processes of Ithonus appear to have been more systematic, and to have sprung from traditions of the antediluvian Benefactors; while the invention of the Dactyli is stated to have been accidentally made during an extensive fire on Mount Ida, which, originating from lightning, was so lasting and intense, as to have melted the iron ores in the soil beneath it—a tradition the same as that which accounts for the name of the *Pyrenees*[6] from a similar fire, which smelted the yet untouched ores of silver in that Mountain-chain.

Ten years after Lucan, the Elder Pliny (Hist. Nat. vii. 56) refers the discovery, upon the authority of Hesiod, one of the oldest Greek writers, to the Idæan Dactyli; but the diverse processes and

[6] Diod. Sic. l. v. 35.

arts of manufacture, he in the same place attributes to the Cyclops, the workmen of Vulcan.

A mythic tradition, of older date than the authorities cited, refers the discovery to the god Vulcan; and another to the Egyptian or Scythian Prometheus: but these are not entitled to the respectability of historic accounts. Only, it may be remarked that the fable of the Lemnian Vulcan, being thrown from heaven by Jupiter, may have had foundation in the actual fall of Meteoric Iron—whose constitution renders it more malleable than any merely cast-iron would be, and whose use we find actual, at the present day, among the Esquimaux, a people not more civilized than were the Greeks in the time of Ithonus. With regard to the agency of Prometheus, who is said to have brought fire and its uses from Heaven, and bound to a rock, expiates through an almost infinite period the rashness of his success, its connexion with iron-making is obscure: it is much more likely that the origin of the fable should have been a corruption of some patriarchal tradition of the real mysteries of the Christian Redemption.

However originating and by whomsoever first worked, the mention of the metal, Iron, as in actual use and affording images of comparison and epithets, occurs in the earliest Greek writers. Homer, the oldest of them, who is placed by the Arundel Marbles at 907 B. C., introduces Achilles, in the funeral

games of Patroclus,[7] as offering a prize of a large mass of iron—so large indeed that the Hero says 'no husbandman need, with that, want Iron in any of his rural pursuits for five years, either for ploughs or for weapons.' The expression, αυτοχωνος, which the scholiast of Eustathius explains to mean *'melted only,'* i. e. without refining or hammering, I once thought inferred a meteoric origin for the mass. In another passage,[8] the plunging of Ulysses' firebrand into the eye of Polyphemus is said to have been, like a piece of Iron dipped by the smith into water, in order *to give it its strength.*

Besides these passages, which are the most direct warrant for the existence of Iron in Homer's time, (and indeed for three centuries before, when we consider his remarkable freedom from anachronisms,) the word Iron is often employed (as for instance Odyssey xxiii. 172) to express moral qualities, analogous to the well known physical properties of the metal.

Hesiod, who flourished about the same time with Homer, also uses the epithet in the same manner as in the line of the Odyssey referred to. He also speaks of Iron in one place[9] directly, though not by the usual words—calling the Helmet of Hercules *adamantine:* which epithet, subsequently applied to mean precious stones, was at first used only to mean Iron or Steel. Mr. Holland, in his treatise on the

[7] Iliad xxiii. 826, etc. [8] Odyss. ix. 391. [9] Scut. Herc. x. 137.

Manufacture of Metals (Cab. Cyclopæd. xxiv. p. 10,) seems to have overlooked this; when he asserts that Hesiod has no where used it except figuratively.

Nearly cotemporary with Homer and Hesiod was Lycurgus, the lawgiver of Sparta, whose iron money, as mentioned by Plutarch (in vit. c. ix.) I see no reason for supposing to be any other metal than what it is there called. The Biographer further mentions the resort to vinegar (which was prescribed for political purposes) to destroy the *stomōma* (which here signifies ductility, or in general *Elasticity*) of the metal, and thus render it inapplicable to any other purpose than a mere symbol of credit. This quite superfluous refinement may serve to convey an idea of the then state of the art: to which, the individual who first afterwards restored the stomōma that had been destroyed, stands in the same relation as the discoverers and patentees of the method of using Forge cinders in the high furnace, do to the Metallurgy of 1820–30.

Not quite three centuries later than Lycurgus, come the poems attributed to Orpheus—which, if really belonging to him, would antedate Homer by nearly four centuries. I have preferred to entertain the doubts of Aristotle, and to assume the latest period which has been assigned to the supposed author. In the poems called Lithica[19] he mentions expressly the ore *Siderite*, or Oreite; which he

[19] Lith. xi. 17. Tauchn. 855. l. Gesner.

accompanies with such epithets as of all the metals could belong only to iron.[11]

In another of the Hymns (lxv.) to Mars, he applies to the god the epithet *adamantine*, which Hesiod had already used to mean Iron.

Nor was this acceptation of the term lost, when, more than a century after, Pindar (who may be supposed to have written about 475 B. C.) used it[12] as applied to a plough. I do not remember to have met with the proper word for Iron, in his poems.

The narrative of Herodotus, about 30 years later, as to the Vase of Alyattes, has been already referred to. So also (Polymn. c. 69,) he speaks of Iron heads, to lances and arrows: which were in the Homeric times more frequently, I believe, brass or copper, as Lucretius has already expressed it:

> Et prior erat *æris* quam ferri cognitus usus.
> And Brass was known and used before was introduced Iron.

Sophocles, who died about 406 B. C., uses[13] the same comparison which we have just seen in the Odyssey—the hardening of Iron in water. From another place[14] we may infer, that the then state of the arts had warranted a special name to be given to *heated* or *red-hot* masses of Iron: although the term there used may have been a mystic, not a metallurgic one—it being introduced in speaking of the same trial or purgation, by carrying masses of red-hot iron,

[11] See also Hymn. xxxviii. to the Curetes.
[12] Pyth. Od. iv. l. 398.
[13] Ajax Flagell. l. 665.
[14] Antigon. l. 270.

success in which was thought, in those early times, as fifteen centuries later, to belong only to Innocence. Finally, in the same tragedy to which I first referred l. 836, the poet uses the phrase 'iron-devouring whetstone,' in making Ajax speak of his sword—the sword of Hector—which had just been sharpened for his meditated suicide.

Aristotle, whose death may be placed about 322 B. C., introduces the mention of this metal in several places, among which I shall cite particularly only two or three.

In his book entitled Meteorologica, he enters[15] into an explanation of the causes of solubility and insolubility in general; and particularly applies it to iron, which he characterizes as most difficult to be affected by heat, and not at all (in this sense) by moisture. The whole passage, though not exactly in accordance with chemistry more modern, yet serves to shew that he had opportunity of making experiments upon the identical substance, Iron.

In the preceding chapter of the same book, he enters into more detail concerning the manufacture: and says, that 'in the working of Iron, it melts upon the application of heat, and again becomes hard: in this way they make (σιμώματα) pure iron'—a word which I give in the original, because I shall have occasion again to refer to the term.

'For the scoria or impurities by these means are

[15] Meteorol. l. iv. c. 7.

deposited; and by frequent meltings and remeltings the material becomes pure, and its ἔμμιμα is produced. These successive meltings, however, are not made too often, for they are always accompanied by a loss of weight on the purer article. But that iron' he adds 'is the best, which requires the least refining.'

In the next sentence, and apparently as if its connexion with iron suggested it at that moment, he speaks of a stone, called in his language, *pyrimachus:* whose nature is more fully explained in the next passage I shall quote.

This is from his book (de Mirabil. auscultat.) of Remarkable Accounts,[16] and I shall translate it in full.

'There is said to be a method of manufacture peculiar to the Chalybian and Mysian (or Amisenic) Iron. The ore is obtained among the sands of the rivers and their tributaries:[17] which some say they merely wash and put in the furnace; while others report, that they put along with it also the earthy and other particles, which have been by repeated washings separated from the mine, and reduce all together—throwing in at the same time the stone *pyrimachus*, as it is called, of which in that region there is great abundance.'

This passage requires no further remark at present,

[16] Opp. tom. i. p. 1158. E. Ed. Paris, 1619.

[17] I give here the original that every one may translate it for himself: Ταυτην δε οι μεν ἁπλῶς φασι πλύνοντας καμινεύειν· οι δε την υποθεσιν την γενομένην εκ τῆς πλύσεως πολλάκις πλυθεισαν συγκαιειν·

than that it helps to clear up the obscurity, which, I before observed in a note, hung about the country of the Chalybes. The claim of this people, who with some authors carry their antiquity back to the time of Abraham, to be considered the discoverers of the method of working Iron, rests upon such foundation, that it was not thought worth while to advert even to it. But that they very early, and at least before the time of Aristotle, did manufacture it, there is no doubt. Some modern writers, among whom may be mentioned Hassenfratz and perhaps Landrin, have placed them, upon the authority of Justin[18] mainly, and Pliny, in Spain, upon the river Cobe. D'Anville, upon the authority of Strabo,[19] locates them in ancient Pontus, or part of modern Armenia, 'in the deep vallies and precipitous mountains, still called Keldir.' The corrected reading of the passage of Aristotle just now given (viz. Amisenic for Mysic) confirms this view—the Amisenic bay in the Euxine Sea forming in fact the northern boundary of this Chalybia, and furnishing its out-port. But what I apprehend would establish it beyond a doubt, is the mention, not before noticed, so far as I am aware, of the stone Pyrimachus (q. d. *fire supporter*.) This, I take to mean nothing else than Bituminous Coal: and the occurrence or non-occurrence of this article, in the respective countries, to be a geognostic proof, either favorable or adverse. It would have required

[18] Just. xliv. 3. [19] Lib. xii. c. 3.

researches, not otherwise justified in this Report, (even if the present state of our geological records would have at all furnished the information,) to have ascertained the presence of bituminous coal in Armenia; the existence, however, of bituminous springs and lake-like deposites, as also of salt, well ascertained, would indicate a proximity, at least, to coal-measures in that region; while, as far as the exact position claimed for the Chalybes, in Spain, can be made out, there is no likelihood of coal having ever occurred. This subject, however, I leave now for others to examine.

Passing over three centuries from Aristotle, we find in Diodore of Sicily,[20] a mention of a peculiar method of manufacture among the Celtiberians, in Arragon; which was 'to bury rods of Iron in the ground, and leave them until in time the rust should eat out all the weaker particles of the metal, and leave only the strongest and purest. Out of this so prepared, they manufacture their excellent swords and other arms: these swords in particular are so keen, that there is no helmet or shield, which cannot be cut through by them.'

I leave here the strict chronological order to remark, that Plutarch, who died about A. D. 140, gives the same account of the same people's manufacture. This is, in fact, a method still pursued in Japan; and is given by Swedenborg as one way to

[20] Lib. v. c. 33.

prepare steel.[21] I insert in a note[22] the remarks of Mr. Holland on this subject.

The last Greek author, whom I shall cite, is Strabo; who, dying about A. D. 25, may be considered as bringing the testimonies down to our era. He speaks[23] of the great quantities of ore, which had been extracted from Chalcis and Eubœa,—the property of the Athenians. This had been carried on to such extent, and so long, that the mines were beginning to be exhausted.

The same author speaks[24] of the iron, furnished by Great Britain to the Romans. The introduction of the art in that island is attributed, and perhaps

[21] See Beckmann: iv. 242.

[22] 'Whatever may be thought of the idea of converting Iron into Steel, by interring it for any given period, a belief that the metal acquires tenacity by such a course, obtains among the workers in these metals generally; and more especially was this the case formerly. Certain of the old Sheffield cutlers, who had credit for making first rate articles in their day, were in the habit of placing bundles of steel in the mud of some water course for a few weeks; by which means, the metal was alleged to be much improved in quality. And it is common for Scissor-smiths, when they get steel that has a tendency to break on the punching of the hole for the formation of the bow, to place it in a damp cellar for a few weeks; by which treatment, having rusted considerably, it generally becomes fit for use.

But however Steel may improve in quality, it loses much of its weight by oxidation; hence in the vast quantities that are exported to America from this country, it is not only customary to wrap the bundles in rope-paper, and place them in boxes, but actually to oil every bar; in order, not merely to preserve its smooth appearance, but more particularly, to prevent that loss of weight, which would take place if the material were allowed to rust during its transit.' Holland: Manufactures in Metal, vol. i. pp. 13, 14.

[23] Lib. x. c. 1. [24] Lib. iv. c. 5.

with reason,[25] to Odin: the claim to priority over all others, asserted for the same hero by the Gothic traditions, is not, however, entitled to the same consideration;—that claim not finding written assertion until 1,000 years after the period of which we are now treating, when the Sæmundian Edda was composed.

An account of the isle of Elba[26] is the last reference to this author, that need now be made. The period at which the Elba ores were first opened, must be very remote—M. Karsten supposes it to have been about 700 B. C.: and in Strabo's time they had already ceased to smelt the iron on the island, but carried it, as they do now, to the mainland. The Greeks called it *Æthalia*, from the blazes of the iron-works: and under that name, Aristotle, in the treatise of Remarkable Accounts already cited, speaks of it; though he does not refer (as indeed it would have been unsuitable for him to have done, in that connexion,) to the Manufacture of Iron.

Having now brought down the testimonies of the Greek writers, the mention of the isle of Elba carries us easily to an inquiry of the Roman authors, who have treated of the subject. As however, even the oldest of these are modern, compared with those

[25] It is to be wished, that the Society of Northern Antiquaries, of Copenhagen, who have already published some interesting researches, would take up the legends of Odin, and illustrate and explain them.

[26] Strab. Lib. v. c. 2.

among whom we have been just now conversant, and as all the Latin legends and mythology, in this regard, have been taken from the Greek, it will be sufficient if we cite only those authors cotemporary, or nearly so, with our era.

There is only one, Pliny the Elder, (whose death is placed A. D. 79,) who has treated expressly on this matter. Merely mentioning then, that Livy[27] has recorded the fines, imposed by Cato the Censor, on the Celtiberian iron-works, after the Spanish war, (194 B. C.) and[28] the edict of Paulus Æmilius after the Macedonian war, (about 14 years later,) forbidding in Macedonia Proper, Thrace, etc., the working of any metals, except iron,—I shall give here entire the interesting chapter of Pliny the Elder, which contains the substance of what was known upon the origin of the Iron Manufacture, and also a view of its existing state in his time, a half century after the Christian era.[29] He says,[30] after

[27] Hist. xxxiv. 21. [28] Hist. xlv. 29.

[29] Not to interrupt the continuity of the text, I refer in a note to the testimony of Julius Cæsar, the invader of Great Britain; which is prior, by a century, to the writings of Pliny. He says, 'Utuntur—annulis *ferreis* ad certum pondus examinatis, pro nummo.' De Bell. Gall. v. 12. 'They—the Britons—use *iron rings* (or plates,) guaged to certain weights, as money.'

Mr. Scrivenor, in his History of the Iron Trade, now in process of publication, refers to several of the old British Chroniclers, as well as to the iron antiques, which have been discovered in the Forest of Dean, and elsewhere in England and Wales, as proof of the early introduction of this manufacture into the island: the enlargement of which, he dates about the period of the visit of Adrian, A. D. 120, and supposes the principal establishment to have been at or near Bath.

[30] Hist. Nat. Lib. xxxiv. 39.

having given a long account of the origin of the manufacture in brass:—

'We shall next give some details in regard to the metal, Iron; which has furnished the best and the worst instruments in the hands of man. With this we plough, we dress our fields, we set our orchards, and every year renew the youth of our decaying vines. With it we build our houses, we excavate rocks; indeed to almost every use, Iron is applied. But with the same also we carry on war, commit murders, perpetrate bloody robberies; and that not always hand to hand, but converting the metal into a missile, whether from machines, or by the arm, or (as arrows) even feathered; which last I look on as the most atrocious perversion of human ingenuity,—as if Death did not always come quickly enough, but we must also lend it wings. But the fault of this use does not necessarily belong to nature; and several times efforts have been made, to restrict its employment to those cases wherein it is innocent. Thus in the treaty, which Porsenna gave to the Romans after the expulsion of their Kings, we find it expressly provided, that nothing Iron shall be used except in agriculture. Also, some of our oldest writers have warned us of the danger that attends using an iron Style, for writing. And the edict of Pompey the Great, passed in his third consulship, (after the Clodian Riot,) is still extant, forbidding any weapon to be worn in the City.

'Iron has certainly sometimes been applied, however, to practical purposes, more honourable and less repulsive than in the shape of arms. Thus the artist Aristonidas,—when he wished to express the fury of Athamas subsiding, after the death of his son Learchus, into sorrow,—used a mixture for the statue of Iron and brass; that in the very material (the *redness* of the iron being seen, as it were, through the polish of the brass) might be expressed the blush of his mortification and repentance. This statue exists at Thebes at this day. In the same city is to be seen a Hercules, in iron, by Alcon;—the patience and labours of the god being indicated in the nature of the metal. We have also in Rome bowls of iron, in the temple of Mars the Destroyer; the nature of which deity seems to be expressed in this circumstance, inflicting the punishment of rust even on the Iron itself, and by a malignant providence, doing nothing in human affairs except for harm and destruction.

'Iron ores[31] are found almost every where, and

[31] In the original *metalla*. Anciently there were no other ores dug, but those which answer to what we now call *metalliferous*. From the circumstance of their being dug up in pieces, one piece after the other, (*alla met' alla* in Greek,) came the name *metal:* which has, in modern Chemistry, been restricted to a particular division of minerals. It may be remarked, that it was only in times much later than Pliny, that the word *metallum* came to be used, in the sense in which we now employ its English equivalent, or to mean any thing but *what was dug out piece by piece*, i. e. an ore.

That use may have been, however, all the time, made by the Eastern nations; if the conjecture of Mr. Parkhurst is correct, as to the meaning of the Hebrew and Arabic word, (*metel,*) which he interprets to signify, to *forge* or hammer

are very plentiful in the island of Elba; they can be easily traced by the tinge which they give to the soil: and the processes for refining the metal are nearly every where the same. In Cappadocia only, it is a question whether the Iron comes from the water or from the ore, since it has to be washed in a particular stream, in order that when put in the furnace it may produce Metallic iron.

'The differences of different kinds of metallic iron are quite numerous; seeming principally to arise from the nature and exposure of the ores. Some are very soft, and more nearly answering the purposes of lead; others brittle, like brass, and especially to be avoided for wheel-tires, or nails, for which the first kind answers best. Another kind does only for small things—such as ordinary nails, and especially shoe-tacks: while another would rust too soon for this. All of this last kind bear the name of *stricturæ;* a word not applied to other metals,[38] and derived from its peculiar property of taking an edge (*a stringendâ acie*). There is also a difference in the furnaces made use of; in some the ore is treated so as to furnish the Iron in bars—

out. The word *metel* in Job, xl. 18, is taken to mean a *forged bar*;—in our translation, a bar of Iron.

[38] Brotier, in his note on this passage, says: Hoc omne *ferreum metallum—la mine de Fer*—stricturæ vocabatur;—a stringendâ acie—*la trempe.*

The text here speaks of Ferrum—the *metal;* not *ferreum metallum*, the *ore* or *mine.* Virgil to be sure uses it in this last sense:

Stricturæ Chalybum—Æneid. viii. 421.

in others they cast only anvils, the heads of hammers, etc. [33]

'There is much difference too in the water, in which when hot it is plunged and tempered.[34] Advantages in this particular have, at different times, given reputation to different places for excellence in iron—as[35] Bilbilis and Turiasso in Spain, and Comum in Italy: although in none of these places is there

[33] I give here the original, that each reader may put his own interpretation upon the passage.

Et Fornacum maxima differentia est: nucleusq. quidem ferri excoquitur in his ad indurandam aciem: aliquæ modò ad densandas incudes, malleorumve rostra. Plin. Hist. Nat. Tom. vi. p. 103, Edit. Barbou. Paris, 1779.

[34] However this may be in fact, it is an opinion still prevalent among skilful and practical workmen. In a large shop in Sheffield, famous for the excellence of its saw blades, I once noticed a peculiar appearance in the water of the tempering vat: and the reply to my inquiry, as to what was mixed with the water to cause the appearance, was, that it was their secret. Frequently, there is more or less grease mixed with the water, except for *files*. I do not remember to have ever seen any thing but pure, though stale water, used for them.

[35] 'Approaching the Ebro,' says D'Anville, 'Bilbilis, the native city of the poet Martial, near a river named Salo, (now Xalon,) is only known by the name of Baubola, in the neighbourhood of a new city built by the Moors, called *Calatayud:* Turiasso still exists in Tarragona.'

Martial concurs in the testimony of the text, when he says, (Ep. Lib. i. 50):

Videbis altam, Liciniane, Bilbilim
Equis et armis nobilem.
* * * * *
Tepidi natabis lene Congedi vadum,
Mollesq. nympharum lacus;
Quibus remissum corpus adstringas brevi
Salone, *qui ferrum gelat.*

Comum is the modern Como; the birth-place of Pliny the Younger. The lake, near which it stands, has lost its ancient name of Larius, and is now the *Lago di Como.*

any ore. But of all others the best is the Serican[36] iron, which is imported with their silks and skins; and next to it, the Parthian. These are the only two kinds, to which a tempered edge can be, without any subsequent process, given: all other sorts are too soft in their mechanical arrangement and texture. In our continent, sometimes the ore makes the excellence, as in the Norican[37] iron: and sometimes the manufacture, like the Sulmonian. As in stones for the sharpening, the oil-stones, and those hones which are used with water, differ from one another—the oil-stones giving a finer edge, (and what is remarkable, in the first product from the ore, the iron, which seems to be first made softer by throwing water on it, becomes afterwards brittle and spongy,)—the tempering of the small blades is done with oil, lest water might harden them into too much brittleness. The blood of man seems to be revenged, as it were,

[36] The uncertainty, in which the Geographers have found and left the position of Serica, does not allow more to be said here, than that it lay somewhere between China and Hindostan—perhaps near the modern Thibet. D'Anville has thought it of consequence enough to write a special memoir; which may be found in the Memoirs of the Academy, Tom. xxxii.

This Serican iron may have been somewhat the same as the modern *Wootz*, which comes from a neighbouring, or perhaps the same, region.

[37] The ancient Noricum covers the ground of Austria, Styria, and Carinthia. Other authors testify to the reputation of the Iron brought thence: so Ovid, Met. xiv. 712.

Durior et ferro quod *Noricus* excoquit ignis.

The natural resources still remain in their ancient excellence; but either in comparison, or actually, they are not availed of as formerly.

Sulmo, the birth-place of Ovid, still exists in *Solmona*.

on iron; for touched by a drop, it quickly contracts rust.'

He speaks then, by the way, of the Magnetic properties of Iron—the only metal which can acquire such properties; and mentions the project of Dinochares, who proposed, and actually commenced building, a temple, in which an iron statue of Arsinoe, the sister of Ptolemy,[38] was to be suspended in air, by the equilibrium of several magnets acting against gravity. Its completion was broken off by the deaths both of architect and patron.

He thus[39] continues:

'Of all metalliferous ores, those of Iron are by far the most abundant. In a district of Maritime[40] Cantabria, washed by the ocean, there stands a mountain, steep and lofty, entirely of this material; as we have already before said.

'Iron, by heating (unless it is hardened by hammering) becomes soft. When merely red it is not proper for being hammered; it should be taken at

[38] This was Ptolemy II., also called Philadelphus; the founder of the Alexandrian Library: and the patron of the Septuagint Translation of the Scriptures. He died about 246 B. C.

The Dinochares here mentioned has been often, (but improperly, and lately by the American editors of Lemprière,) confounded with Dinocrates, who re-built the temple of the Ephesian Diana.

[39] Cap. xliii.

[40] This district is the same with the modern Biscay: and the mine here spoken of is that of the present Sommorostro; where the strata are really in thickness from 8 to 10 feet, and yield under present management 40,000 tons of iron yearly, according to Mr. Worcester, who however must be in error. Beudant calls the ore, specular oxide, or *fer oligiste*.

a white heat. Rubbed with vinegar or alum, it becomes like brass.[41] It may be kept from rusting by (cerussâ) chalk, or gypsum, or melted pitch. This is the mixture called by the Greeks *antipathia:* though some say that the effect may be produced by some mystic influence or witchcraft; and that there is still a chain over the Euphrates, near Zeugma,[42] used by Alexander the Great about his bridge, all the new links, subsequently put into which, are eaten by rust, while the old ones are entirely sound and clean.'

There follows then some remarks, as to the medical uses and properties of Iron; which do not illustrate our present purpose farther than to shew, that the metal was known, and of varied application. They are therefore omitted.

Besides this long passage, expressly devoted to the subject, it is also mentioned in various places by the same author: thus in lib. xxviii. 9, he speaks of iron or steel instruments, for either lithotomy or lithotrity, it is not explained which; and in chap. 23 of the same book, he speaks of razors (literally

41 I rather think this has allusion to methods of bronzing. The author has not given the whole of the recipe.

42 This town was formerly the principal passage of the Euphrates, and hence its name, which means literally the Bridge. D'Anville says there is still, on the other side, a little place called *Zegmâ*.

The chain mentioned here, with all its links, has long since yielded to an influence, before which even that of witchcraft, hinted at by Pliny, must bow. Brotier's note on this passage asks, with great naivetē;—Fuitne priscis—ars ita ferrum fundendi aut temperandi, ut rubiginem non sentiret?

the knives of the barbers) becoming dull in consequence of circumstances, which we do not, it is true, hold to have much influence.

Cotemporary with Pliny was the Philosopher, or Impostor, Apollonius of Tyanæa; whose life, though in fact written by Philostratus, nearly 200 years afterwards, yet being a mere rifaccimento of materials collected during the life-time of the subject himself, is entitled to assume its chronological place here. His friend Damis, the real author of the life, mentions[43] his having received from a certain Brahmin seven metallic rings, for the different days of the week, according to the respective dedications of the said days and of the metals. Thus the Iron one was worn on Tuesday.

Confirmatory of the accounts of Pliny, it may be mentioned that the explorations of Pompeii have furnished articles of this metal, though the conditions of their fabrication do not appear to have been investigated: and the Count de Caylus informs us of a small statue of Hercules, in cast-iron, found in the Museum of the Villa Borghese, evidently of Etruscan origin, and probably dating three and a half or four centuries before the Christian era.

Such are the statements which have come down to us of the ages preceding our computation of time: and with them, I shall close the ancient History of the Manufacture of Iron.

[43] Philost. iii. 41. Beckmann, T. iii. 56.

I will nevertheless avail of the long interval, of nearly fifteen centuries, between the date to which we have now arrived, and the publication of the first modern work that can be called a Treatise on Iron, to make a few remarks, which I hope will be thought not out of place, upon the methods which have been already mentioned by Aristotle, Pliny, and Plutarch, as existing among the Chalybes and Celtiberians.

It has been the general opinion, that these people made use of furnaces either without a chimney (for fusible ores, after the Catalan method,) or with a very low one, for ores rather more refractory. In the first case, malleable iron, or steel, might be made by the one process: in the second, it was attained by the repeated fusions, or finings, which Aristotle mentions. Both kinds, however, would belong to the class called by the Germans *stück-ofen*, and by the French *fourneaux-a-masse*, such as were used, in comparatively late times, in Silesia: in which the reduced metal, after heat applied for a longer or shorter time, according to the charge, would be found (as in the crucible-analysis of ores at present) in an ingot at the bottom of the furnace.

I confess, however, that after considering the passage of Pliny, (the original of which I have given in the note, p. 40,) I do not see that his language excludes the idea of a *fluss-ofen*, in the nature of what we term, in modern times, a high furnace; out of which the iron is run while yet fluid.

In regard to this passage, M. Beckmann (t. iv. p. 240) says: '*Stricturæ* was the name given to pieces of steel completely manufactured, and brought to that state in which they were rendered fit for commerce. In speaking of other metals, Pliny says that the finished products of the works were not called Stricturæ, (this was the case for example with copper) though sharpness could be given to instruments of other metals also. The words last quoted are read different ways, and still remain obscure. I conjecture that he meant to say, that some steel-works produced things which were entirely of steel, and that others were employed only in *steeling*.'

The author of the Treatise on the Manufactures in Iron and Steel in the Cabinet Cyclopædia[44] (which is, I believe, to be attributed to Mr. Holland,) says of this passage, that 'the words, whatever they mean, are not to be construed, as if they had been written by a modern cutler,—the welding of an edge of steel to a body of iron, or the fastening it by other means to that or other substances.'[45]

Both these writers appear to me to have sought for *steel* in places where it need not be found; and where its use would have been equally well sup-

[44] Vol. xxiv. p. 12.

[45] That however the ancients had the art of welding, or otherwise fastening, iron or steel to other metals, appears to be implied in the account already given of Glaucus the Chian. A passage of Diodore of Sicily (l. v. c. 34) in regard to the Lusitanian spears, which he calls ὁλοσίδηροις, or with blades entirely of Iron, may bear also on this subject.

plied with Iron merely. I have before shewn from Plutarch, on the passage concerning Lycurgus, that stomōma does not always mean *steeling*, but generally *elasticity*, or *temper*, of whatever degree; which temper belongs to iron as well as steel: and indeed Pliny himself, has in another place [46] spoken of a stomōma from brass or copper; while writers are quoted elsewhere by Beckmann, who have used the term to mean our modern *forge-cinder*, or in German, *hammerschlag*.

My own interpretation of the passage is, that the *stricturæ* were rods or bars of Iron, (or perhaps steel in some cases,) in such shapes as to be fit to be converted by the smith into wheel-tires (which would be a broad bar,) or into nails, which we call a nail-rod. He has been speaking only of iron fitted for these applications; and he adds, 'all these kinds, suitable for the purposes I have mentioned, are called *stricturæ*.' Farther, these stricturæ were made in some furnaces; while others made plates, larger or smaller, so as to cover anvils or the heads of heavy hammers—or perhaps, as I said at first, *cast* those very articles,—since even at the present day, cast anvils are not at all uncommon, although not good for cutlers.

I may properly terminate this discussion here, in Beckmann's own words: hoping that 'the reader will forgive me for entering into such dry criticisms;

[46] Lib. xxxiv. 25.

but if Pliny's valuable work is ever to become intelligible, occasional contributions of this kind must not be despised.'

Before leaving entirely the subject of ancient furnaces, I will only remark, that the ancients possessed *Bellows* suitable for blowing these furnaces, whether Stück-ofen or Fluss-ofen; though it is not ascertained, who was their inventor. They have been attributed[47] to Anacharsis the Scythian, about 600 B. C. But this is certainly an error, as they are mentioned expressly in Homer, 300 years before, particularly in those passages,[48] descriptive of the visit of Thetis to Vulcan to procure the arms of Achilles. They are also mentioned by the Hebrew prophets, Jeremiah (vi. 29,) and Ezekiel (xxii. 20): both of whom preceded, or were at least cotemporaries of Anacharsis. That they were generally of leather only, appears from Plautus;[49] and in a passage of Virgil's Georgics,[50] from which, and the notes on it, it appears that they had investigated the matter sufficiently to establish certain points as to the *kind* of leather which should be used. But this subject of Bellows, I shall have occasion to mention again.

[47] Strab. lib. vii. c. 3.
[48] Il. xviii. 372, etc.
[49] Fragmenta, Tom. ii. p. 469, Ed. Tauchn.
[50] Lib. iv. 170.

Sec. 2. *Modern History of the Manufacture of Iron.*

For seven hundred years after our era, the mention of this subject by different writers, whose works have come down to us, (such as Clement of Alexandria, Olympiodorus, and others) is not more explicit or satisfactory than the accounts, which we have just come from consulting. About that period, however, may be dated the commencement of some authentic information; which thickens upon our way as we descend to times nearer our own. In exhibiting here their principal details, I shall pursue the same kind of chronological arrangement as in the preceding part of this Report, so as to present the epochs in their proper order.

A. D. 712. The mines of Styria (which is, in part, the ancient Noricum of the Romans,) are spoken of, as being opened again at this time. They used the *stück-ofen* before mentioned: probably the same with the ancient one spoken of by Aristotle.

A little later, the importance of the manufacture, in England, is mentioned by Bede.

950–1000. The use of the same kind of Furnaces, mentioned just now, was general, over Alsatia and Burgundy. 'It must have been later,' says M. Karsten, 'ere they were introduced into Saxony and Bohemia.'

1160. Iron-works at Kimberworth in Yorkshire; recorded in the public archives of Great Britain.

1238. Proclamation of Henry III., touching iron-works in the forest of Dean; preserved in the Rolls office.

1355. Act of 28 Edward III., prohibiting the exportation of manufactured iron. M. Karsten has erred, in referring this to the year previous: he is however correct, in calling it the first *law* on the subject; for it was only in this reign, that the difference was marked between a *proclamation* of the King and council, and an *act*, receiving the assent of the Lords and Commons.

1365. Bloomeries used in Silesia.

1488. Mines of Dannemora in Sweden opened.

1490. The epoch of modern Foundries; from the casting of stoves, then for the first time, in Alsace. The *fluss-ofen*, says Karsten, must have been known at that time; although Agricola, fifty years later, says nothing about them. Hassenfratz also quotes a writer in the Annals of Manufacture,[81] as affirming, that in the latter half of the 15th century there were, in England, furnaces capable of producing sixty quintals, or nearly three tons, of metal in the twenty-four hours. This could only have been from high furnaces, even more improved

[81] See Hassenfr. Siderotechnie: Tom. i. p. 10.

than the *fluss-ofen*. But I have not yet found any confirmation for this statement.

1546. The publication of the work of George Agricola, *de Re Metallica*, or On Metals. Thus, the first regular treatise ever published on the Manufacture of Iron, was so well received, that four folio editions were published in less than twelve years from its first appearance. As I suppose that every Iron-master will take pride and interest in knowing more of this, the first historian of his art, I willingly insert here, from Bayle, some particulars concerning him.

George Agricola was born at Glaucha, in Misnia, on 24 March, 1494. Bred for a physician, and educated in Italy, the opportunities for discoveries in Mineralogy and Metallurgy, found by him amid the mountains of Bohemia, drew him off from his profession; which for a while he practised in Joachimsthal. A pension, bestowed on him by Maurice of Saxony, enabled him to renounce medicine altogether, and to settle at Chemnitz, (then, as now, the great manufacturing mart of Saxony,) where he composed his great work already mentioned, and several slighter ones upon Mineralogy and the connate branches of Natural History, as also upon Weights and Measures. It was at this place, that on 21 November, 1555, he died; and a melancholy shadow rests on the last times of this old man, who for five days laid unburied, not finding, as Matthio-

lus feelingly says, in all his country for which he had done so much, earth enough to hide his sad remains. The fact was, that he had mixed himself up in the disputes then warm, between the advocates and adversaries of the Reformation,—he being a strenuous Romanist,—and had rendered himself so unpopular, that the inhabitants seized upon the opportunity of a poor revenge, in denying him burial. Finally, he was removed and buried in Zeits.

Agricola describes only three kinds of Furnaces, as being in use in his day, and corresponding to the different degrees of fusibility in the ores. I have thought to assist the reader, by giving a drawing of these furnaces; in which, however, I have been obliged to use an arbitrary scale.

The most fusible ores were treated in a kind of hearth, (Plate I. fig. 1.) similar to what is now employed in the Catalan method. 'Those, which were a little less fusible, were heated in furnaces, about three feet high and five feet wide, (fig. 2). The mine, broken up, was thrown together with charcoal into the mouth or tunnel head: and successive charges replaced the materials, as they settled or were consumed. The combustion was kept up with bellows, worked by hand; and after twelve hours of strong heat, they run off the scoriæ, and found at the bottom of the hearth, a mass of Iron

which was carried to the shingling[88] hammer. If the mine was more difficult still to fuse, it was roasted, broken up into small pieces, and smelted in furnaces more elevated, (as well as may be judged from the figures, five or six feet in height); the resulting product was sometimes placed immediately under the hammer, but more generally refined, by another melting, before being hammered.'

These furnaces are all of the kind denominated *stück-ofen:* of the other sort, or *fluss-ofen*, Agricola makes no mention; although we have certain information of their use, in 1490, in Alsace, and also an account, given under the same date, of furnaces still more highly improved.

Finally, it may be remarked of the work of Agricola, that his confinement to one city prevented it from being of much value, as an historical record of matters, out of Saxony and its borders; and that, although from the original remarks, and especially the synthetic, classifying mind of the writer, it was certainly a remarkable book in its age and for its age, yet there is not much in it which would bear translation for the benefit of modern iron-workers. Nevertheless, it is always worthy of being referred

[88] This word, *shingle*, is a curious instance of the corruption of words. It was, no doubt, taken from the corresponding French word—*cingler*—which has technically the same meaning, and generally the signification of *striking* or beating forcibly, and seems to be an abuse of another word, in the same language,—*sangler*,—that is well known.

to, as an epoch in the History of the Manufacture of Iron.

1547. Cannon first cast in England this year.

1550. The *fluss-ofen* for the first time introduced into Saxony. Hans Lobsinger, an organist of Nuremberg, the probable inventor of wooden bellows.

1559. Act of 1 Eliz. c. 15; limiting the consumption of wood into charcoal, for making iron, to the county of Sussex, and part of Kent.

I have not been able to assign any date, for the introduction of *charcoal*, as the combustible, in this manufacture.

1559–1600. Hans-sien, a Voigtlander, constructs in the Harz, a Furnace, twenty-four feet high and six feet boshes.[53] About this time, says Mr. Hebert, blast furnaces in England were of sufficient size, to produce from two to three tons of pig-iron per day, or fifteen to twenty per week. He adds, however, that it was only in the most favourable situations that such great products could be obtained.

1612. Simon Sturtevant's patent, for the use of pit-coal in making pig-iron. By his patent 'he was bound to publish the nature and process of his Invention; which he did, in a quarto book entitled *Metallica*.' He failed, and was succeeded

[53] Hassenfratz, T. i. p. 180.

1613. by John Ravenson, in his zeal and in his patent. This last also failed, and surrendered his patent; at which there may be less surprise, when we are told by him, that he expected to make one ton of pig-metal, with *one* ton of pit-coal.

1614. In Sweden, Gustavus Adolphus promulgates an ordinance to encourage the emigration of German furnace-men to that country. M. Hassenfratz has been inaccurate in referring the date of this act to 1604; which was seven years before Gustavus ascended the throne.

Up to that period, the Swedish furnaces had been from ten to twelve feet in height, and without *boshes;*[54] their place being supplied by a *talus* of sand, put in the bottom of the Furnace. Now, the German artizans, emigrating, brought with them what may be termed the fashion of *middle furnaces*[55] twenty or twenty-five feet high, with boshes, and openings at several heights in the tymp, for the convenience of getting rid of the cinder.

1619. Dudley, following Sturtevant and others in the patent, succeeds in manufacturing Iron with pit-coal; but the prospects exciting much

[54] I apprehend this word to be a corruption of the French, *Bouche*, i. e. a mouth, and to have originated in the era of *low* furnaces.

[55] M. Hassenfratz calls every thing a *High* furnace, which is more than twelve feet.

envy, his patent was taken from him, and even his works destroyed. Long subsequent to this (in 1665,) his son, in his book *Metallum Martis*, lays the burden of the break-up (for it was no failure,) upon the arbitrary avarice of the protector Cromwell.

1620. The usual epoch assigned for the discovery of *wooden Bellows*, (instead of the leather ones,) by Henry, Bishop of Bamberg, in Bavaria. But I have before, out of Beckmann, given a more probable date of 1550; though it is not unlikely, that the Bishop might have been the first to publish an exact description. Nevertheless, it seems certain that in 1621, one Pfannenschmidt, (whether

1621. his real name, or a soubriquet from his trade, cannot now be told,) settled in Ostfield, in the Harz-forest, and began manufacturing wooden Bellows. His art was disclosed only to his son; and thirty years ago, his great-grandson had still the monopoly of the Forest.

M. Landrin has been inaccurate, in his date of 1626; as well as in the name of this person, whom he calls the improver.

1627. Patent of Charles I., for the new Invention of smelting Iron ore with sea-coal, or pit-coal, only.

1640. *Trompes*, or water-blasts, first introduced into Italy. These machines are still used in

many places; but in their operation,[56] the air being *drawn* in, as it were, by the fall of water, takes into mechanical suspension either some particles of water, or of aqueous vapor,—carries them with it into the furnace, and thus produces the greater or less ill-result, which attends *dampness* of the Blast.

In 1662, they were first described by Father Kircher. I have been informed that there is such a machine in use in America, in the State of N. York.

1650. The methods in Sweden, still farther improved by an importation (due to De Gier) of workmen, from Liege and Namur. The furnaces were raised from twenty-five to thirty feet; the boshes, which before had been made in the crucible, or hearth, were now raised entirely above it; and a dam-stone completed the improvement.

1658. Chambré describes, as then for some time existing, the use of peat by the Dutch in the manufacture of Iron.

1674. Mr. Ray, the Naturalist, describes, in this year, the methods pursued at Cuckfield in Sussex; which county, formerly the principal seat of the manufacture with charcoal, has now ceased to give any product, since the introduction of pit coal.

'The hearth, or bottom, of the Furnace is made of

[56] The best physico-mathematical researches, on the subject of these *trompes*, are to be found in the Works of M. Venturi. A translation of one of his treatises, in which these water-blasts are spoken of, was made, I believe, by Mr. Nicholson, and is to be found among the Collection, by Mr. Tredgold, of Tracts on Hydraulics.

sandstone, and the sides round, to the height of a yard or thereabout;—the rest is lined, up to the top, with brick.

'When they begin upon a new Furnace, they put fire for a day or two, before they begin to blow; they then blow gently, and increase by degrees, until they come to the height, in about ten weeks or more.

'Every six days they call a *founday;* in which space, they make eight tons of iron,[87] if you divide the whole sum of iron made by the founday; for at first, they make less on a founday, at last, more.

'Of twenty-four loads of coals they expect eight tons of iron: to every load of coals which consists of eleven quarters they put a load of mine which contains eighteen bushels.[88]

'A Hearth ordinarily, if made of good stone, will last forty foundays, i. e. forty weeks; during which time the fire is never let go out.'

1701. The epoch of the works of Neviamskoï, in the Ural mountains; established by Count Demidoff-Akimsi, under the sanction of Peter the Great.

His furnaces were forty-five feet high; and a systematic saving was effected in fuel; for whereas, they had never before made iron with less than 132

[87] This is considerably below Mr. Hebert's statement, given under A. D. 1559—1600; as also that of O'Reilly, given under A. D. 1490, from Hassenfratz.

[88] These eighteen bushels, it may be inferred, weighed about a ton.

lbs. charcoal to the 100 lbs. iron, and in some places the consumption was 370 for 100—the Neviamskoï works used charcoal in quantities, varying, by weights, from 115 to 170, for the 100 of Iron.

1715. Epoch of Furnaces in Maryland, Virginia, and Pennsylvania. M. Karsten places this in 1730; but this is inaccurate,—1500 tons of pig-iron having been, in that year, imported into England from Maryland and Virginia.

I shall give hereafter a tabular extract from the Returns of Custom, in which this subject will be treated in more detail.

It is certain, that, in 1718, there was upwards of three tons of bars imported from one or the other of these States: and in 1719, an act was proposed, in the House of Lords, to prevent the erection of rolling or slitting mills in America. This act was not, however, passed till 1750.

1721. The Fluss-ofen first introduced into Silesia.

1737. Proposal in the British Parliament to bring all their pig-iron from the American colonies, so as to save the wood on their own Island.

1740. The use of Dudley's method begins to extend the consumption of pit-coal. The Coalbrook-Dale Works established.

Tons.

Product in England, from 59 Furnaces: 17,350

1749. The invention of fan-bellows, or rotary Blast; by a person named Teral.

1750. Act of 23 Geo. II.; taking off the duty from American Iron, (which had been for

pigs, 3*s.* $9\frac{9}{20}$*d.* per ton, and for bars, £2 1*s.* $6\frac{3}{20}$*d.* per ton,) but forbidding the erection of Slitting or Rolling mills in America.

1760. Cylindrical cast-iron bellows, moved by a water wheel, erected by Mr. Smeaton, for the Carron Iron Works, in Scotland.

1769. After this epoch, which is that of Watt's Steam Engine, such bellows became of general use: Landrin dates their universal employment in 1778.

1780. Invention of the Puddling furnace.

'According to the best testimony,' says Mr. Holland, 'the first person, who introduced or attempted this process, was an iron-master, in the county of Gloucester, named Cort; but like too many other inventors, he was unsuccessful, and ruin overtook him before he could turn to his own advantage that scheme, which—presently—became so profitable in the hands of others. The first individual, who succeeded, and derived from it a princely fortune, was a resident of South Wales; who had the judgment to perceive, and the spirit to patronize, the ingenuity of a person, who, acting as his engineer, carried towards perfection, the art of *puddling*. The process was quickly introduced into every part of the country, where the Iron trade was carried on:—the business was rushed into with capitals of £10,000, to £100,000, iron-works multiplied rapidly, the quantity produced exceeded the consumption, competition reduced the price below the

cost of manufacturing, and not a few adventurers had to tell a tale of disappointment and ruin.' This epoch is, by some, referred to a date four years later, viz. 1784; by others to 1785.

1784. Invention of Iron-Rolls:—patent granted to the same Mr. Cort, mentioned in the preceding paragraph. Like the former, it was an unprofitable discovery for him.

		Tons.
1788.	Product in England from 53 coke furnaces; active, ...	48,800
	24 charcoal; active and inactive, . .	13,100
	77 furnaces, ...	61,900
1796.	Charcoal Furnaces almost entirely given up: Product from 121 furnaces, . . Tons,	124,879
1802.	Product from 168 furnaces, . .	170,000
1806.	Product from 227 furnaces (only 159 active at once,)	250,000
1820.	Product (on the authority of Mr. Dufrênoy,)	400,000

Mr. Murray, who makes it 690,000 tons for this year, and 680,000 for 1830, must have been misinformed.

I am not able to assign the exact date of Mr. Hill's patent for the use of *forge-cinder*: I take it to be about this time. Although a useful invention, yet I believe that neither Mr. Hill's employment of it, nor theirs who contested his patent, had been the first or the second time of its use.

Samuel Rogers mentions it in 1819, in those letters which are spoken of in the Introduction to this Report.

1826. According to M. Dufrênoy, there were in the commencement of this year, in all, 374 furnaces in Great Britain, Scotland, and Ireland; of which 271 were in activity: the product from 262 of which was . . . . . Tons 581,367
The other 9 at the same average of 2,219 tons per furnace, ... 19,971

Product from 271 furnaces: 601,338

The same writer affords the authority for the following table, shewing the proportions of different kinds of Iron, viz:

	Tons.	
Finery iron, or for Bars, . . .	339,662	
Iron for 2d fusion, or Castings, .	172,250	
Pig-iron, ...	89,426	
		601,338

1827. Product from 284 Furnaces: 690,000 tons.

1829. Era of the introduction of the Hot-Blast: patent enrolled March, 1829. The Inventor, Mr. Neilson, thus speaks of it (in 1836,) in a letter to Mr. Telford.

'About seven years ago I received information that one of the Muirkirk Iron furnaces, situated at a considerable distance from the Engine, did not work so well as the others; which led me to conjecture that the friction of the air, in passing along the pipe,

prevented an equal volume getting to the distant furnace, as to the one situated close by the engine. I at once came to the conclusion, that by heating the air at the distant furnace, I should increase volume in the ratio of the known law of expansion.'

This was tested by an experiment in a smith's forge: forthwith experiments were commenced at the Clyde Iron Works; which, being completely successful, led to its adoption at the Calder, and many other works.

'The air, as at first raised to 250° F.' Mr. Neilson goes on to say, 'produced a saving of three-sevenths in every ton of pig made; and the heating apparatus having since been enlarged so as to increase the temperature of the Blast to 600° F., a proportional saving of fuel is effected: and an immense additional saving is also acquired by the use of raw coal, instead of coke, which may now be adopted.

'By the use of this fuel, with three-sevenths of the fuel formerly employed, the Iron-maker is now enabled to make one-third more iron of superior quality.'

This last position has been doubted: in another place the evidences will be brought together and compared.

		Tons.
1830.	Product of Iron in the United States of America, ...	191,536
1833.	Dr. Cleland states the whole product of Great Britain, at	700,000

But this I should think is much under-estimated.

1834. Three Charcoal furnaces still left in England.

1836. Dr. Ure states the product in this year to have been . . . . . Tons. 1,000,000

1839. There were still *two* charcoal furnaces left in England at this date, according to information given me; whose products were absorbed in some particular manufactures,—especially those where steel is made by *contact*, as is the case with fire-irons generally.

As well as I could ascertain from different sources, the whole number of furnaces, in Great Britain and Ireland, may be set down at four hundred and eighty-four; to which, in the spring of 1840, may be added forty-seven in process of construction. Mr. Johnson of Liverpool, estimated September last, as contemplated to be commenced in 1839–40, sixty new furnaces in Wales, and twenty-six for Scotland alone; exclusive of thirty-one actually building in the former, and seven in the latter district, which will thus have more than tripled its number in fourteen years.

In 1826, Scotland had	25	furnaces:	17	in blast:	8	inactive.
1839, " "	55	"	50	"	5	"
1840, we estimate	88	"	77	"	11	"

The precarious state of all trade renders it impossible to fill up the last two columns for this year, with accuracy.

Of the whole number of furnaces just now mentioned (484), there were in activity at once 445 furnaces; producing . . . . . Tons. 1,250,000

This I take to be a near approximation of the truth.

The following tables, compiled from a Parliamentary Report of July, 1839, may be interesting; as shewing the present state of the commerce of Great Britain in this article.

I. FOREIGN IRON, IMPORT AND EXPORT.

WHERE SENT.	1835.	1836.	1837.	1838.
	TONS.			
Foreign iron imp. from Sweden	13,787	16,646	11,215	15,543
Russia and elsewhere, . .	5,963	8,387	8,057	7,464
Foreign steel; principally from Sweden, ...	969	1,065	423	497
Total *imported*, . . .	20,719	26,098	19,695	23,504
Foreign iron exported U. S. A.	595	2,302	918	2,053
Elsewhere, ...	2,040	2,460	1,700	2,316
Steel, ...	1,361	965	341	648
Total *exported*, . . .	3,996	5,727	2,959	5,017
Foreign iron consumed, .	16,723	20,371	16,736	18,487

II. DOMESTIC IRON EXPORTED.

WHERE SENT.	1835.	1836.	1837.	1838.
	TONS.			
To the U. States, of the following kinds: .				
Bar iron, exclusive of bolts and rods, ...	29,124	48,812	29,864	48,594
Pigs & castings, (prop. 3:1)	16,074	20,878	13,842	16,120
Wrought iron, nails, &c.	4,286	6,573	3,657	4,657
Unwrought steel, . . .	1,886	1,952	1,477	1,636
Bolts and rods, . . .	590	1,115	366	222
Total export to U. States,	51,960	79,330	49,206	71,229
Elsewhere; of all kinds,	147,046	113,027	145,085	184,789
Total exported, . .	199,006	192,357	194,291	256,018

III. BRITISH HARDWARES AND CUTLERY EXPORTED.

WHERE SENT.	1835.		1836.		1837.		1838.	
	Quantity in tons.	Declared Value in £.	Quantity in tons.	Declared Value in £.	Quantity in tons.	Declared Value in £.	Quantity in tons.	Declared Value in £.
United States, . .	11,062	978,491	12,058	1,318,412	4,916	574,876	6,805	661,704
Elsewhere, . . .	9,135	854,552	9,014	952,901	8,456	885,931	8,490	836,623
Total, ...	20,197	1,833,043	21,072	2,271,313	13,372	1,460,807	15,295	1,498,327

IV. MANUFACTURE OF CRUDE IRON IN FRANCE DURING 1836.

	No. FURNACES.		MATERIALS CONSUMED IN TONS, (ENGLISH.)						PRODUCT IN TONS.			No. Men employed.
	Whole No.	Active.	Mine.	Cinder.	Charcoal.	Wood.*	Coke.	Coal.	Pig.	Castings. 1st fus.	Total.	
Charcoal Furnaces,	488	419	742,395	: :	361,965	29,190	: : :	: : :	223,250	38,755	262,005	6,089
Coke and Coal, do.	29	20	108,142	5,457	: : :	: : :	60,842	54,221	36,149	2,147	38,296	529
Coke and Charcoal,	5	5	21,766	: :	7,017	: : :	3,503	: : :	6,994	1,068	8,062	156
Totals, . . .	522	444	872,303	5,457	368,982	29,190	64,345	54,221	266,393	41,970	308,363	6,774

* The cubic metre or *stère* of wood averages 815 kilogrammes = 1793 lbs. English, or almost exactly 0.8 Ton.

The last table on the opposite page, I have reduced from the report of the French minister of Public Works, for 1837, laid before the Chambers in 1838, to shew the advances, which France has of late years made in this branch of National industry; aided much by the efforts and surveillance of a government, which takes scientific men under its protection. The effects in this manner produced in spite of local embarrassments and difficulties, and the economy which they have been able to introduce into the old methods, (which in many places are retained, because circumstances do not allow of any substitution,) would of themselves deserve a special report.

Comparison of the product of Iron in France during several successive years.

Denomination.	1833. Tons.	1834. Tons.	1835. Tons.	1836. Tons.
Cast-iron,	237,000,	269,064,	295,000,	308,363.
Bar-iron,	152,265,	177,163,	209,539,	210,580.

This is not enough for the consumption of the Empire; and therefore in 1836, France imported:

	Tons.	
Pig-iron,	19,962,	principally from Great Britain.
Bar-iron,	4,759,	principally from Russia and Norway; of this only 99½ tons were *rolled* Bars, and made with *coal*.
Steel,	1,057,	(unwrought) chiefly from Sweden.

I also present here the following table of the

Product of Iron in Europe and America.

	Tons.	
England, 1839,	1,250,000.	m. p.
France, 1836,	308,000.	Pub. Doc.
Russia, 1830,	167,500.	Villefosse.
Sweden, 1830,	150,000.	Karsten.
Austria, 1830,	100,000.	Karsten.
Prussia, 1830,	80,000.	Virlet.
The Harz Mountains,	60,000.	Virlet.
Holland and Belgium,	60,000.	Virlet.
Italy,	50,500.	Virlet.
Spain,[59]	18,000.	Virlet.
Norway,	13,500.	Karsten.
Denmark,	13,500.	Virlet.
Bavaria,	13,000.	Virlet.
Hungary,	10,000.	Murray.
Saxony,	8,000.	Virlet.
Poland,	7,500.	Virlet.
Switzerland,	3,000.	Virlet.
United States of America, 1839,	235,000.	m. p.
	2,547,500.[60]	

[59] See note p. 42.

[60] Mr. R. C. Taylor, whose information upon such matters is entitled to much respect, has made a statement (which has been communicated to me only while these sheets are passing through the press) somewhat differing from mine.

He arranges, upon the authority of a recent author, the product of Great Britain as follows:

	Tons.
In England,	636,000.
In South Wales,	550,000.
In Scotland,	200,000.
	1,386,000.

But he afterwards puts this amount down in gross at . . 1,512,000 tons. I have not, however, seen reason to alter the quantity I have given. Bel-

It has not been the policy of the British Government to encourage manufactures in any part of British America. With regard to Central and South America and the West Indies, I have no authentic information. The same may be said of various nations of Asia and Africa, who according to the testimony of travellers, such as Gmelin, Mungo Park and others, use methods, (from which we may draw or correct our ideas regarding those of classical antiquity,) that in a measure supply their wants.

On the river Gambia the furnaces of the Camalians are ten feet in height; but discordant accounts are given of the amount of their product.

gium, he sets down at 147,640 tons. This estimate, which is upon later authority than I had consulted, I assume as more worthy to be received.

But the product of the United States he regards, upon the estimate of Mr. Lea, to have been in 1837, ... 250,000 tons. In this I cannot accord.

Dr. Ure, who has given a similar table in his Dictionary of Arts and Manufactures, but upon the authority of M. Virlet, has suffered a slight inaccuracy to escape him in the summation of the amount; which in the original is given in Quintals, but which he has expressed in Tons. The quintals in question are the *metrical* quintals, i. e. one hundred kilogrammes; and the kilogramme is, as nearly as may be, 2.21 pounds avoirdupois; so that 10 metrical quintals are almost exactly 1 ton English. Hence Dr. Ure's amount in tons, for 13,433,000 quintals—the whole production stated by M. Virlet,—should be 1,343,300 tons, instead of 672,000 tons, as the article in the work referred to gives it.

Sec. 3. Manufacture of Iron in Maryland.

No materials exist from which could be compiled an authentic history of the special Manufacture of Iron in this State. Such details as I have been able to collect orally or otherwise, from sources that could be relied on, I here present;—with the hope that it may induce contributions from persons, who may have some additional information and to whom I have not had access.

The epoch of Furnaces in this State has been already given as of the year 1715, and the exportation of Iron appears to have occurred first in the year 1717. It is very probable that some of the furnaces I shall presently mention, situate near the Western Shore of the Chesapeake, go to this early date. But the first authentic record, which I have met with, is among our Council-proceedings [61] under date of 23 August, 1756; where, in a report of the Governor and Council to the British Commissioners of Trade and Plantations, there is stated to be *eight* furnaces and *nine* forges in operation.

Again on 21 December, 1761, in a similar report, there is said to be the same number (*eight*) of furnaces, making about 2500 tons of Pig, and *ten* forges, capable of working up 600 tons of Bar iron.

[61] Lib. T. R. & U. S. p. 118, etc.

Mr. McMahon, in his History of Maryland, carries it, upon the same authority, as far back as 1749; when there appears to have been the same number of furnaces and forges.

The reports, although desired by the commissioners to be annual, do not appear to have been made regularly; or it might not have been thought necessary to insert them among the Council Proceedings. I do not find any farther mention of this manufacture or its amount down to the year 1771; beyond which I have not thought it worth while to examine.

The motion made in the British Parliament, in 1737, to import all their Iron from America, so as to spare their own forests has been already mentioned; and either its rejection, or the operation of antecedent causes which produced that rejection, led to the adoption of methods that in the general use of bituminous coal rendered such a policy unnecessary. Indeed, the other extreme was now in part resorted to; and the act of 23 George II., as already mentioned,—although it professed to be for the encouragement of the manufacture in British America, and did in fact take off the duties from American Pig and Blooms,—forbade the erection of any mills or machinery for laminating, slitting or otherwise treating forged iron.

Mr. Smollet[62] has already noticed the remarkable circumstances attending the passage of this bill, in the numerous and contradictory petitions and memorials presented in relation to it. From Sheffield, the *Tanners* represented 'that if the bill should pass,

[62] Smollet: Hist. England, B. iii. c. i. § 35.

English iron would be undersold: consequently a great number of furnaces and forges would be discontinued: in that case the woods used for fuel would stand uncut: and thus their trade be deprived of *oak-bark* in sufficient quantity for its support.' In more natural and nearer connexion with the subject, the Iron-masters and manufacturers from the same district alleged the great expense to which they had run in erecting their establishments and their consequent claim for protection, as well as the claims of the labourers and others now in their employment, who they assumed would infallibly be thrown out of work should the bill pass; because of the advantage which the greater plenty and cheapness of wood would give to the American manufacture. Neither of these classes objected so much to the remission of the duty on Pig-iron: because the oak-bark consumers thought, that as the furnaces diminished in consequence of imported Pig being cheaper, forges would increase;—which last were also the kind of establishments in use about Sheffield. Nevertheless the government was warned by the latter class, that the main object of the Bill,—to diminish the importation from Sweden,—would not be attained, because the American iron was inapplicable to the purposes for which Swedish iron was wanted: And it was also suggested 'that if all the Iron manufacturers of Great Britain should be obliged to depend for their supply of Pig-iron from the Plantations, (which must ever

be precarious from the hazards of the sea and foreign enemies,) the manufactures themselves would probably decay, and many thousand families be reduced to want and misery.'

The Birmingham Iron-dealers however, in their petition, asserted directly the reverse;—affirming the American iron to be as good in all respects as the Swedish: that consequently it could supply its place, and thus save much money to the nation; because while the Swedes were paid in hard money, which they laid out again directly with the enemies of Britain—the French,—the American colonist would receive pay for his iron in British manufactures of various kinds: that Great Britain did not now produce half enough to carry on the manufacture, and therefore having to import it, it made no difference to the domestic iron-smelters whence it came: nevertheless in view of every thing that could be said, and specially with regard to compelling the colonist to take his pay *in kind*, they prayed 'that the Americans might be restrained from erecting any rolling and slitting mills or forges for making plates, as that would interfere with the manufacturers of Great Britain.' The act was finally passed as these last recommended.

I do not know of any immediate local effect produced by this act, except in the tradition that a rolling and slitting mill belonging to Mr. Edward Dorsey, on the Patapsco, and near the present

Avalon Works, was in consequence stopped. But this has not full confirmation in any existing documents.

It is probable that at this era, nearly all the establishments which I am about to mention, as near the Chesapeake bay, were in existence. As there is no documentary evidence by which their chronological succession can be fixed, I shall arrange them in the order of their geographical position, beginning in the north-eastern side of the state and progressing westward.

First in Cecil county was the Principio furnace, on the Creek of the same name and near the present stack of Mr. Whittaker. This furnace claims a high antiquity, and was probably one of those originally erected by British capitalists. A part of its hearth is still standing.

The erection of a forge on North-East, commonly called Russell's forge, and now carried on by the proprietors of Principio Works, may be dated about the same time. But I have not been able to find any reference to the precise epoch of either establishment.

In Harford county was the Bush furnace, belonging to John Lee Webster, not far from the village of the same name. But of this I have no farther information, than that in August, 1767, it was advertised for sale in the Maryland Gazette.

Of another furnace, called Onion's, about one mile from Joppa, there is in the same paper under date of August, 1769, a more full description; but it is more on account of the local advantages than of the Works themselves, which do not appear to have been very extensive. About this era, (from 1765 to 1770) seems to have been an unfortunate time for the Maryland furnaces,—at least those in the district under consideration, if we may judge from the frequency and earnestness with which they were exposed to sale.

In both of the last mentioned establishments, the ore and particularly the wood are represented as being in great abundance; but the great difficulty with all seems to have been in the kind of labour, of which they made use. The hands employed were either convicts transported and indented here, or *redemptioners* as they were termed, viz: those whose services were sold for a term, to re-pay the expense of their passage. The unsettled condition of affairs about the time I have designated, is shewn by the number of advertisements in the same Journal already referred to, offering rewards, greater or less, for fugitive labourers of this kind, and slaves. I have been told, that seven or eight years later, the facilities which these persons had of enlisting in the army of the Revolution contributed no little to the cessation of more than one iron establishment.

Next in Baltimore county came the Hampton or Northampton furnace, erected by Messrs. Charles,

John, and Charles Ridgely about 1760. The latter name was the one by which it was most publicly known for the first ten years of its existence, if we may judge by the newspaper. The instrument of co-partnership of the three proprietors bears date on 28 October, 1761; but the buildings were probably erected before, inasmuch as on 28 February, 1760, a return was made of a writ of condemnation, which Charles the Elder had, with curious caution, sued out and laid to cover one hundred acres *of his own land*:—thus setting it apart especially for Iron works, and defeating any actual or supposed right of the Lord Proprietary to assume in virtue of his Palatinate,[63] the European *royalty* over mines of precious and other metals. To the same proprietors of this establishment belonged also the Long Cam forge on the Great Gunpowder. This forge I believe to have belonged at first in great part to persons in England, and to assert a higher antiquity than the furnace. Both forge and furnace stopped many years since.

On Stemmer's Run, was another furnace, about seven miles from Baltimore: and on Herring Run, the so called Kingsbury furnace.

These are all east of Baltimore. But on Jones' Falls, close to the city, and on the site of Bradford's mill, was the Mount Royal forge.

[63] The act of May session, 1719, ch. 15, though not exactly applicable to this case, was yet, I suppose, in view of the proprietors, in this proceeding.

On a branch of Gwynn's Falls stood the furnace of the Baltimore Company; belonging I believe, at one time, to a Mr. Dorsey, but now to Richard Caton, Esq.: and on the Patapsco, near Elkridge Landing, was the Elkridge furnace of Mr. Edward Dorsey, (who also owned the rolling mill at Avalon before mentioned,) now belonging to Andrew Ellicott, Jr. Esq. The forge to the Elkridge furnace is still in existence, and I believe used at Avalon.

Where to locate the York furnace, belonging to Mr. Swope, an advertisement concerning which I have met with in the Maryland Gazette for 1765, I am ignorant;—the advertisement not defining the locality precisely.

In Anne Arundel county, Thomas, Richard, and Edward Snowden owned the Patuxent furnace, and the Patuxent forge, now belonging to Messrs. E. T. Ellicott & Co.

The Curtis creek furnace, now Barker & Son's, was I believe later than the epoch of which we are writing, and younger than the preceding. It was built by William Goodwin and Edward Dorsey of Avalon; and becoming the property of the co-partners (of whom Mr. Goodwin was one) in the Hampton furnace, was in the adjustment of their affairs, sold to Mr. Barker.

Ten or fifteen years before the Revolutionary war, the manufacture of iron in Frederick county is supposed to have had its origin;—first introduced by

'foreigners or persons now unknown, and at a period somewhat later (1770–90,) actively encouraged by Messrs. James, Roger, Thomas, and Baker Johnson. The particulars which follow are derived from James Johnson, Esq. now of Baltimore, himself a descendant of this public-spirited family, and are generally in his own words.

Old Hampton furnace, on Tom's creek, about two miles west of Emmetsburg, but built by persons whose names have not survived, may be dated in 1760–65. It was soon discontinued for want of good ore; and its seat is now occupied by a mill.

'Legh furnace was built at nearly the same time, by an Englishman, Mr. Legh Master, at the head of Little Pipe creek, two or three miles south-west of Westminster; and shared the fate of Old Hampton. I have understood,' says Mr. Johnson, 'that it did not make more than one or two blasts,—the ore proving unproductive, and the Iron indifferent. The site and part of the lands are in the possession of Messrs. Isaac and Thomas Vanbibber.'

Catoctin furnace, situate about twelve miles north-west of Frederick-town, and within a mile of the present furnace-stack, 'was built in the year 1774, by James Johnson & Co. and was carried on successfully until the year 1787;' in which year, the same company erected the present furnace 'about three-fourths of a mile further up Little Hunting creek, and nearer the ore banks. This was carried

on by James Johnson & Co. until the year 1793, when a division was made between the brothers, by lot. The Catoctin fell to the share of Thomas and Baker Johnson;—two-thirds to the former and one-third to the latter: who carried it on, not very successfully, until 1803, when Baker bought out the two-thirds of his brother, and rented it to Benjamin Blackford, for ten years, at £1,100. At the expiration of Blackford's lease, the property was sold by the executors of the proprietor to Willoughby and Thomas; and was, after their dissolution of partnership, carried on by Willoughby Mayberry, until the year 1820, when it was sold by trustees to John Brien, who made very expensive improvements. It is now in the possession of the heirs of Mr. Brien.' The furnace was blown out in November or December last; and I understand is not expected to be in blast again this year.

The yield of the old Catoctin furnace is stated by Mr. Johnson, to have been from twelve to eighteen tons per week; and the yield of the present is supposed to have been not materially different. The ore which is worked, is brown hœmatite, containing in its cavities more or less phosphate of iron. It has been represented to me as expensive to raise; and the quality of the metal produced not of first grade. In the ore also is associated carbonate of *zinc;* and the separation of this last metal has been very successfully effected, during the

fabrication of the national standards of weight and measure, by M. Hassler.

Shortly after the erection of the first Catoctin furnace, (say in 1775–6,) the same proprietors erected on Bush creek, about two miles above its mouth, the Bush creek forge. 'It consisted,' says Mr. Johnson, 'of a finery and chafery, and made from three to four tons of iron per week. A slitting and rolling mill was also erected, at the spot now known as Reel's mill;—but after being carried on for a few years, was abandoned. The forge became the property of Col. James Johnson, and was kept in operation until 1810, when it was discontinued. The Baltimore and Ohio Rail Road now passes directly over the place of the hammer wheel.'

About the same epoch with the present Catoctin furnace, was erected by the same proprietors another furnace, situate on a small stream, one mile above the mouth of Monocacy, and called Johnson furnace. It was supplied with ore from the beds adjoining the Point of Rocks: whence the material was delivered by wagons, and by boats on the Potomac, jointly. The product did not exceed twelve or fifteen tons per week: but the iron was of good quality. 'Upon the division of the property, Johnson furnace fell ultimately to the share of Roger Johnson; who carried it on until some years after 1800.'

In connection with this furnace, Roger Johnson 'erected on Big Bennett's creek, about five miles above its junction with the Monocacy, Bloomsbury forge. This forge had a finery and chafery; and the weekly product was between four and five tons. It was also carried on very profitably, for a year or two, by working up *stamp-stuff* from the cinder heaps of old Catoctin.' It was discontinued about the same time with Johnson furnace.

'Fielderea furnace was erected by Fielder Gantt, three miles south of Frederick-town, on the Harpers Ferry road; it made a blast, but the ore being unproductive and the iron of indifferent quality, it shared the same fate as old Hampton and Legh furnaces. The lands were divided into wood-lots, and sold out in the years 1791 and 1792. There is now a good grist-mill on the old furnace site, belonging to the family of the late John Hoffman, of Frederick-town.'

Such are the particulars which I have been able to obtain, concerning the manufacture of Iron in Frederick county.

In Washington county, the Messrs. Johnson were hardly less active than in Frederick county. As far back as 1770, James Johnson, before mentioned, superintended (for Mr. Jacques and Governor Johnson, under the firm of Jacques and Johnson,) the erection of 'Green Spring furnace, situate on Green Spring run, within one mile of its entrance into the

Potomac, and one mile from old Fort Frederick. It was carried on a few years; but the ore was not productive, and the iron of inferior quality.

'Licking creek forge, on Licking creek, and near its mouth, was built by the same firm and under the same direction, after the erection of Green Spring furnace; by which it was supplied with pig-iron. Some time afterward, it was sold to Mr. Chambers, of Chambersburg, who carried it on for several years, with pig supplied from his furnace in Pennsylvania.

'Mount Etna furnace, on a branch of the Antietam, five or six miles north of Hagerstown, was built by Samuel and Daniel Hughes, about the same time with the Green Spring furnace; and was carried on successfully for many years.'

This furnace is remarkable, as having cast, for the first time in Maryland, *cannon* during the Revolutionary war. 'An eighteen pounder of its manufacture is now lying on Barracks Hill near Frederick Town.'—It was discontinued before the beginning of this century.

In connection with this furnace, and not more than one mile and a half distant, the same proprietors also built the Antietam forge, about four miles north of Hagerstown; which, after the stoppage of the furnace, was for some years supplied with pig-iron from Pennsylvania.

The present Antietam Works were built by Messrs.

Henderson and Ross, about 1775–80. After carrying them on successfully many years, they came into possession of the family of the present proprietors. These works will be again mentioned, in speaking of the existing establishments in Maryland.

It may not be amiss to present here, in one view, a list of those furnaces in Frederick and Washington, about which I have not thought myself allowed to omit the interesting particulars given above, together with their respective dates, and the names of their first proprietors. I hope that if any omission shall have been made, or any date given too vaguely, those who may have more exact information will communicate it to me.

Iron Manufactories in Washington County.

Date.	*Name.*	*By whom erected.*	*Discontinued.*
1770	Green Spring Furnace,	Jacques & Johnson,	about 1775
"	Licking Creek Forge,	do.	do. 1780
1771	Mount Etna Furnace,	S. & D. Hughes,	do. 1795
"	Antietam Forge,	do.	do. 1800
1775–80	Antietam Works,	Henderson & Ross,	still active.

Manufactories in Frederick County.

1760–65	Old Hampton Furnace,	——— ———,	1765–6
1762–65	Legh Furnace,	Legh Master,	1765–6
1774	Old Catoctin Furnace,	Jas. Johnson & Co.	1787
1775–76	Bush Creek Forge,	do.	1810
1787	Catoctin Furnace,	do.	still active.
1785–90	Johnson Furnace,	do.	1800–5
1787–90	Bloomsbury Forge,	Roger Johnson,	1800–5
1789–90	Fielderea Furnace,	Fielder Gantt,	1791

From these details, which I have collected as to the early iron manufactories in Maryland, I shall pass to an account of existing establishments.

In speaking of these, I shall pursue the same order of geographic position, in which I have treated of their predecessors. First, then, comes the Principio furnace; belonging to Messrs. G. P. Whittaker & Co., situate on Principio creek, and very near the track of the Philadelphia and Wilmington Rail Road.

The present furnace stack, which is about one hundred and fifty yards lower down the creek than the ancient one before spoken of, was built by Mr. Hughes about the year 1800. It was injured and partially destroyed, during the occupation of the adjoining district by the British, in the war of 1812; but was subsequently repaired and carried on by the same proprietor, until 1817–18. It then went out of blast, and so laid until 1836, when it was purchased, together with a large body of land, by its present proprietors, who have conducted it successfully ever since.

The stack itself is thirty-three feet high, from the hearth to the charging plate; and the diameter of the boshes is eight and one-third feet. The water of the creek furnishes the motive power (about fifteen horse-power) of the blast, which passes into the furnace through one tuyère pipe, under an average pressure of 1¼ pound per square inch. The

trundle-head is also provided with an apparatus for heating the air; which is used or not, according to circumstances, and the train in which the furnace is desired to be put.

The ore used at this establishment comes principally from the beds near the Spring Gardens, Baltimore; from whence it is carried by water to within four hundred yards of the furnace. It came nearer, before the rail road passed between the landing and the furnace-yard. A part also comes from Iron Hill, near Elkton. The former is an altered carbonate of iron, and yields upon an average from 35 to 40 per cent. The latter is represented to me as a brown hematite, giving from 45 to 50 per cent. The specimen which I have seen, however, I should consider as a siliceous carbonate of iron. The flux used here with these ores is oyster-shells.

The average annual yield is estimated at 1100 tons.

In the same county (Cecil) and situate on the North-east river, is a furnace, not now in blast, erected in 1810 by Messrs. Sheredine and Russell. It was run only about four years, till 1814.

The forge on the same stream (the old Russell forge before mentioned) is now carried on by the proprietors of the Principio works: as well as the Elk Iron-works, situate on the Elk, about four miles north of Elkton. These last are mills only for the manufacture of sheet iron, boiler-plate, and nails. The crude iron from Principio is used up at these

two establishments. All these works together give employment to not less than 150 labourers and artisans.

Of the rolling-mill, on the Octorara, belonging to Mr. Roman, as well as of the forge,[64] about four miles above, on the same stream, belonging to the heirs of Mr. James Hopkins, I present here no particulars: as these manufactures do not form part of the subject of this Report. The same is to be said of the forges of S. Stevens & Co. situate on the river Elk; which I have not yet visited.

The next establishment is the La Grange Iron-works, on Deer creek in Harford county, belonging to Messrs. J. Rogers and Son. This consists of a furnace and forge; the latter erected by Mr. John Withers in 1832, the former by the present proprietors in 1836. The furnace is, I presume, about twenty-eight feet in height from hearth to charging plate: the boshes are six feet in diameter. The water of the creek is used to drive the blast; which is *cold.*

The ore, which is a brown hematite of good quality and yielding about 50 per cent. of iron, is procured from beds distant six miles, in a south-westerly direction, from the furnace. The flux is lime-stone, obtained about one mile farther than the ore banks, in the same direction. The average

[64] Since writing the text, I am informed there is at the same place a furnace-stack; which is not, however, in blast.

annual yield is estimated at 1170 tons; and the bar-iron is stated to be excellent.[65] Of the forge I do not offer any details; but the entire establishment employs about 72 men and 29 horses and mules.

Harford furnace, belonging to Messrs. Patterson, was erected in 1830, but has been during the winter of 1839, taken down for the purpose of rebuilding. Of it, therefore, I do not present any account, nor of the other works connected with it, which do not come within the scope of this Report.

On Curtis creek is situated the furnace of Messrs. J. Barker and Son, on the site of the establishment before mentioned of Messrs. Goodwin and Dorsey—the precise date of which I cannot give.

This furnace is thirty feet high, and nine and a half feet boshes. The blast is driven by the water of the creek, which also turns three other wheels for different purposes connected with the establishment. The machinery for the blast furnishes about nine hundred cubic feet per minute through one tuyère-pipe; whose structure presents a peculiarity that merits attention. The diameter of the nozzle is at the extremity six inches: in which nozzle, works (by a lever regulated from without,) a plug of five and a quarter inches in diameter. The withdrawal or approach of this plug, in regard to the extremity of the nozzle, increases or diminishes the area of the circular zone through which the air is driven into

[65] Ducatel: Geolog. Rep. 1838, p. 5.

the furnace, and thus regulates with more delicacy than the ordinary throttle, the quantity of air furnished; while the greater diffusion of the blast is supposed (and I think with probability) to leave ample room for all its useful effect, with less danger of any deterioration or derangement in the hearth, attendant upon too great pressure and sharpness of the entering current.

The ore used here comes in part from beds near to the furnace, and in part from the same locality which furnishes the Principio furnace. The flux used is oyster-shells: and the iron produced at this establishment has a high character for toughness and tenacity.

At the same place there is also a foundry, erected in 1829, belonging to Messrs. Barker; who likewise have one in the city of Baltimore, that dates as far back as 1810. These two foundries convert into castings about two-thirds of the quantity made at the furnace. This quantity, in an average blast of nine months, is estimated at 1100 tons. The entire establishment employs through the year 150 men and 30 horses and mules. The facilities which its situation gives it for water-carriage much diminishes the expense in the latter regard.

Close by the mouth of the harbour of Baltimore, and on Locust point, is situate the Patapsco furnace, of Messrs. E. T. Ellicott & Co., erected by them in 1835. The height of this furnace is thirty feet, and

diameter of boshes six feet. It is blown, like all the furnaces I have mentioned, with one tuyère; and the motive power to the blast is a steam engine of twenty horse-power.

The ore comes mainly, I believe, from the locality before mentioned; but some used to be procured from beds at the furnace. The average product per annum is rated at 1000 tons.

This furnace is worthy of remark from the mode of its structure; which is both more economical and more effective than the ordinary way of building used in Maryland. The arrangements in connection with the preparation of charcoal, which is made in *ovens*, are also worthy of note. I cannot doubt but that, under suitable management, a considerable economy must attend their use.

Connected with this furnace are puddling furnaces and roughing-rolls: which use up all the pig made by the furnace, and furnish the bars to be re-manufactured, to the Avalon Works.

The same proprietors own also the Patuxent furnace, erected by themselves in 1831–2, at the site of Snowden's forge on the Little Patuxent, which has been before mentioned. The height of this furnace is twenty-eight feet; the diameter of the boshes eight feet. The blast is driven by the water power of the stream through one tuyère, and with the pressure (usual through all the Maryland furnaces) of 1¼ pounds per square inch.

The ore comes from points near to the furnace and is an altered carbonate, in which are associated crystals of the peroxide of iron. It is smelted with facility, and yields 50 per cent. of iron. I believe that use has also been made of the forge-cinder, which had accumulated in considerable quantities at the spot. The flux of both furnaces is oyster-shells: and their average duration of blast, nine months.

Like the Patapsco furnace, there are puddling furnaces and roughing-rolls here also: and the annual product, estimated at 1200 tons, is converted into bars, and sent to the Avalon Works to be finished.

The Avalon Works are exclusively devoted to the manufacture of bar-iron. I present therefore no particulars in regard to them, except that their capacity is rated at the fabrication of 4500 tons per annum: and that, in connexion with the two furnaces just now described, not less than 360 labourers and artizans, and 150 horses, mules, and oxen are employed.

In 1826, the Elkridge furnace was erected by Andrew Ellicott, Jr. and Brothers, near Elkridge landing. The furnace is thirty-two feet high, with boshes of eight and a half feet. The blast is driven by water from the Patapsco, and is carried into the furnace by one tuyère.

The ore occurs in the vicinity; and I believe the position of the race for the water wheel is favourable

for the transportation of some considerable quantity. It is of the same character with the ores all along the western verge of the Chesapeake.

The duration of the blast is from nine to ten months: and the average annual product, which has been stated to me at 1400 tons, is almost entirely produced in castings of various kinds, principally water and gas pipes. The iron is of good quality; and I have had occasion to notice the advantage of its being mixed with some other pig to produce castings of the second fusion, in which the maximum of stiffness and tenacity was desirable.

This establishment gives occupation to at least 100 hands, and 50 horses, mules, and oxen.

I believe that at the Savage Factory, on the Patuxent river, and connected with the Baltimore and Washington Rail Road by a branch railway, a furnace has been recently erected. But I have not had opportunity to ascertain any particulars or results. At the same place a foundry has been for some time in successful operation.

In regard to the Catoctin furnace in Frederick county, and the Antietam Works in Washington county, I have not been favoured with any particulars to add to what I have already said in regard to their past condition.

As far back as 1833, in a report made jointly by my colleague, the State-Geologist and myself, the

importance of the Coal-region of George's creek and Jennings' Run in Allegany county, was pointed out specially with regard to the manufacture of iron: for which local circumstances, similar to those which have proved of such valuable occurrence in Wales, seemed to shew an extraordinary aptitude. The attention of capitalists having been drawn to this region, many charters of incorporation were procured; and in 1839, the George's Creek Company commenced the manufacture of iron, (almost for the first time in America) with coke, and subsequently with raw coal. Their furnace erected at Lonaconing, about eight miles south-west of the National Road at Frostburg, is fifty feet high and fourteen and a half feet boshes, blown by a Steam engine of 60 horse-power, through two tuyères. The air was heated by stoves placed near the tuyère arches, and attained a temperature of 700° F., and was driven, under an average pressure of 2¼ pounds per square inch, in quantity to 3200 cubic feet per minute.

The ores, which are carbonates of iron, were procured from drifts a few hundred yards from the furnace, and yielded an average of 34 per cent. of metallic iron. The flux was the carboniferous limestone obtained from the same hill. Connected with the furnace is also a foundry, for making machine and other castings.

The average weekly product of this furnace was 75 tons: and the whole establishment gave employ-

ment to upwards of 220 hands and 20 horses and oxen.

In the same coal-basin, and about nine miles north-east of Lonaconing, I am informed that another chartered association, called the New York and Maryland Iron and Coal Company, are about to erect furnaces, similar in dimensions and capacity.

On the waters of Bear creek, a branch of the Yohogany river, and near the village of Friendville, was erected in 1828-9, by proprietors acting under a charter, the Yohogany Iron Works, consisting of a furnace and two forges. Although situate in a coal region, the abundance and cheapness of wood induced the manufacture of iron with charcoal; but I believe that the want of suitable communications, which were of public interest and were anticipated to be constructed within a shorter date than events have justified, rendered the cost of the article when at its market too high, to allow a proper remuneration to the establishment. Since 1834, I think it has been inactive. I am not in possession of documents to show its capacity or results when in operation.

The preceding pages give account of all the furnaces on the Western Shore. There remains only one on the Eastern Shore to be spoken of: this is the Naseongo furnace, situate on the Naseongo river, about five miles from Snow-Hill, in Worcester county; erected I learn by Mr. Mark Richards,

of Philadelphia, in the year 1830, but now belonging to Mr. T. A. Spence. The information which I have in regard to it, is not more recent than 1834; before it passed into the hands of the present proprietor.

The ore used is *bog-ore*, coming from a locality about one mile north-west of the furnace. I believe this is the only instance in Maryland of the employment in quantity of this kind of ore; which is easily smelted, but does not yield over 29 per cent. of iron. The average annual product was, at the date I have mentioned, 700 tons, during a blast of about eight months in the year. It is probable that this quantity is increased, under the personal supervision of the present owner.

For particulars relating to the average cost of charcoal iron in Maryland, I refer to another chapter; and what has been already said comprehends the most satisfactory account of the subjects treated of, which circumstances have allowed me to prepare.

CHAPTER II.

Metallurgic and Geographic Distribution of the Ores of Iron.

A FULL account of the minerals with which iron is associated, so as to form a considerable or principal part, has been given by M. Berthier in his Traité des Essais par la Voie Sêche, and by Dr. Thomson in his Outlines of Mineralogy, Geology, and Mineral Analysis. But this account includes as well those which are used in the manufacture of iron, as those which furnish materials for the other branches of the arts, and those finally which are objects of scientific interest or curiosity. It will be sufficient for the purposes of the present Report, that I include only the former class; which may be called *workable iron ores:* and that in their order, I classify them in the respective proportions of simplicity, with which the metallic iron is associated with other substances.

Although not literally an *ore* of iron, (i. e. not mined as such) yet capable of being *worked* as such when procured, may be placed:

1. NATIVE IRON:—The testimonies as to the occurrence of this substance appear to be too direct

and unexceptionable, to warrant our withdrawing our belief in its existence. Besides the specimens mentioned by Dr. Thomson,[1] M. Schreber is said by Dr. Ure to have discovered a well-characterized specimen near Grenoble; Professor Olmsted has included an instance of it, (the piece weighed two pounds,) in a description of minerals found in Randolph county, N. C., though this is more likely, I think, to have been meteoric; and Professor Silliman[2] mentions a mass upwards of three thousand pounds, which had been forwarded from Trinity river, Louisiana, to New York. This last has however since been determined to be of meteoric origin.

The specific gravity of specimens from Canaan in Connecticut, Dr. Thomson states at 5.95 to 6.72; the weight of water being 1.

Although other substances may be by accident mechanically associated with the iron, in its chemical constitution it may be considered pure metallic iron.

2. Meteoric Iron, (or as some have called Native nickeliferous Iron, from its always containing *nickel*) has been found in various parts of the globe: and as it has in some cases actually been worked, it is not excluded here. A remarkable specimen was discovered by Pallas on the Jenisēi, in Siberia, where the Tartars had reverenced it as

[1] Outlines, &c. vol. i. p. 431. [2] Journal of Science, vol. iii. p. 45.

sacred; and Don Michael Rubin de Celis discovered at Otumba in the old province of Chaco, near Buenos Ayres, in 1783, a mass weighing three hundred quintals, or about fifteen tons. 'On cutting off pieces,' says the writer,[3] 'I found the whole full of cavities, as if it had been formerly in a liquid state. I was confirmed in this idea, by observing on the surface of it the impressions as of human feet and hands, of a large size; as well as the feet of large birds, which are common in this country. Though these impressions seem very perfect, yet I am persuaded they are either a *lusus naturæ;* or that impressions of this nature were previously on the ground, and that the liquid mass of iron falling on it received them.'

There was still in the British Museum, in October, 1839, a large piece of Meteoric Iron, (weighing 1400 or 1500 pounds,) which was supposed to be a part of this identical meteorite; as also a piece detached from the Siberian discovery of Pallas. Besides these there are as many as *twelve* different localities, represented by iron of this or the preceding sort, in the cases of the Museum. More than one place in Africa, Bohemia, Saxony, the Milanese, Mexico, and Brazil, have all sent their contributions. There may be also seen a knife and harpoon made of meteoric iron by the Esquimaux;

[3] Phil. Trans. 1788, p. 37.

and brought in by Captain Parry, I believe, from Davis' Straits.

The meteoric mass or *thunderbolt* from which, in 1620, the Shah Jehanguire had fabricated some excellent sabres (which case I alluded to, when I said it had been actually worked) is more remarkable from the curious mention which the Shah makes of it in his autobiography,[4] than for its size, (which was only five or six pounds,) or any other circumstance.

There is a peculiarity in meteoric iron, that it is not liable to *rust*.

Its specific gravity is 7.3: and in six analyses, which Dr. Thomson gives, the proportion of nickel varied from 1.5 to 8.58 per cent. The chemical proportion of union or association is probably, as stated in the same place,[5] 10 atoms of Iron united with 1 atom of Nickel.

3. Magnetic Iron Ore.—This is so called because (except the titaniferous iron ore from Brazil) it is the only ore of iron attracted by the magnet, without the application of heat.

The mode of its occurrence, although its geological position is in the primitive formations, is very varied; it being found sometimes in beds, as in Savoy and Piedmont, the Tyrolese and Vosges; sometimes in bands or a series of bands, as at Dannemora in Sweden, Arendal in Norway, in the

[4] Phil. Tran. 1808, p. 202.

[5] Outlines, etc. vol. i. p. 488.

Ural mountains, etc.; it forms the mass of considerable mountains, as at Taberg in Smoland; and is also worked, as in the kingdom of Naples, near the sea, in small grains, in the character of sand.

The available deposites, of the greatest reputation, of this ore are in Sweden, which furnishes from it annually to Great Britain a quantity of iron not less than 16,000 tons; to be there employed principally in the manufacture of steel. Its superior tenacity and elasticity are by Mr. Tredgold attributed to the methods of making it; it being shingled altogether under the hammer, instead of the squeezers and rolls of the English manufacturer. The peculiarity of the ore itself, and its exemption to a great degree from any admixture of earthy and foreign matters, (Dr. Thomson found only 1½ per cent. of silica associated with the peroxide of iron,) has in all probability the greatest influence. The methods of manufacture are nearly the same in all the Swedish establishments, and the workmen were transplanted from those to the Siberian works of Count Demidoff; yet the value set upon the iron from Dannemora and Neviamskoï is by no means the same, there being five or six brands which are between them.

This ore occurs also in several localities in Maryland, along the primary range in Cecil, Harford, and Baltimore counties; and also, Dr. Ducatel has found it on Parr's Ridge, in Carroll county: but I believe no deposite has yet been found sufficient to warrant

its being worked for metallurgic use. It was at one time worked at Schooley's mountain, New Jersey.

The specific gravity of a pure specimen was found by Dr. Thompson to be 5.092; and its chemical composition has been determined by the same operator and the Swedish chemist Berzelius, to be 1 atom or equivalent of Iron united with 1½ atoms of Oxygen; thus constituting the most simple known compound of iron with any other substance.

4. Specular Iron Ore.—This is also called by the French mineralogists *fer oligiste;* the mineral being itself *almost* iron. It occurs both among crystallized and sedimentary rocks; and varieties of the species may be found, apparently of daily formation, amid the lava of Vesuvius, and in ancient and existing solfaterras, as of Tolfa and Guadaloupe. The most celebrated deposite of it is in the island of Elba, where it has been worked for more than two thousand years; but there are other very striking localities: such as Gellivara in Lapland, and Sommorostro in Biscay, where it forms (as the preceding class,) the massif of large mountains; Framont in the department of the Vosges, the only point in France, I believe, at present furnishing it; Norberg in Denmark, and the Minas Geraes in Brazil, where it exists in very extensive beds; and finally, like the magnetic ores, as sand upon the shores of the island of Elba, whence it is exported under the name of *poulette.*

It is met with also in many places in the United States: at Montague in Connecticut, is a very considerable deposite, according to Mr. Hitchcock; in the basin of the Monocacy, and on the Catoctin mountain in Maryland, it also occurs; and Mr. Tyson speaks of a favourable locality near Liberty, avail of which, however, the scarcity of fuel on the spot and difficulty of transportation from it hitherto have prevented from being taken.

The metal from this ore is much esteemed, and is hardly inferior to that produced from the magnetic oxides. From this was made the Celtiberian iron, which we have seen was so celebrated in ancient times,—a fame from which the Bilboa blades have not detracted; and, indeed, in many of the Swedish mines it is associated with, and in the working is not separated from, the magnetic ore.

Under the name of *red hæmatite*, too, the ores of this class are widely extended; they form those important deposites in Cumberland, England, so useful to mixture with the more southern ores, and constitute the principal part of the mining about Lauterberg and Altenau in the Hartz.

The *compact red iron ore*, occurring at Lavoulte in France, in veins fifty to sixty feet thick, belongs also to the same class, as well as *red ochre;* which last is sometimes used with advantage to mix with poorer ores.

The specific gravity of the specular ore, the type of

this class, is 5.251; and when pure, it is entirely a peroxide of iron. It is chemically composed, then, of 1 atom of Iron united with 1½ atoms of Oxygen.

5. Fibrous Brown Hæmatite.—In the ores of the preceding classes, the iron has not been found united, except accidentally and to an unimportant extent, with any other substance save oxygen. We come now to a class where Water is a permanent additional element, in proportion from 10 to 15 per cent., in the constitution of the ore. To this, Dr. Thomson has given the name of Hydrous Peroxide of Iron; it is the *limonite* of M. Beudant and others; and the views of both will be preserved, by taking as the true type of the class the *fibrous brown hæmatite*, long known in our own region.

This type and a variety, the *compact brown hematite*, furnish a great part of the iron of France; the deposites in Lancashire, about Whitehaven, in England, which are of enormous extent, are a variety (the *reniform*) of this class;—the *oolitic* variety, in which small globules, or egg-like masses, are held together by a calcareous or argillaceous cement, covers a considerable extent in Burgundy and Lorraine, and is found also in Carinthia and Styria;—the *granular hydrates*, or ferriferous sand, are worked to advantage in the department of Doubs and in Normandy in France, in parts of Switzerland, in Silesia, Bavaria, Poland; and finally, as *bog-iron ore*, it is profitably mixed with other ores,

as in the lowlands of Silesia and Livonia, or used alone, as at Naseongo in this State. I do not know that the *brown ochre*, (strictly so called) belonging to this class, which furnishes a pigment and is used in other branches of the arts, has been employed to aid in the production of iron; though it is very capable of rendering important assistance.

Varieties of this species, somewhat altered by atmospheric exposure or other circumstances, have been also extensively worked in Maryland; as at the Hampton furnace, at the Harford furnace, where it is carried from a point near the Baltimore and Susquehanna Rail Road, and at the Lagrange furnace, in Harford county; at the Catoctin furnace, in Frederick county, where it is associated, as before said, with carbonate of zinc; and near the Point of Rocks, where the Potomac cuts through the Catoctin mountain, whence it is taken for the use of the Antietam furnace in Washington county. At the last mentioned locality, it is earthy and ochreous, constituting what is termed by the workmen, *pipe ore.*

Generally, in all of this kind of ore at the eastern base of the Catoctin mountain, there is more or less of an earthy phosphate of iron, filling the cavities of the mass.

The specific gravity of the type is 3.922, according to Haidinger; and in chemical constitution is composed of 1 atom of Water, 1 atom of Iron, and 1¼ atoms of Oxygen: or, for the purposes of this classi-

fication, it may be considered as 1 atom of Water with 1 atom of pure Specular oxide. There are always associated from 3 to 10 per cent. of impurities, which are made up (in proportions nearly equal) of silica, alumina, and manganese. In the *bog-iron ores*, there is generally present more or less phosphate of iron. Such is the case at the Naseongo furnace.

6. Carbonate of Iron.—I have taken this as the type of a class, more widely extended and more productive than any other on earth. It is variously known under the names of *sparry iron ore*, *fer spathique*, *argillaceous iron ore*, and *siderose*: but there may be made of it two principal divisions, the crystalline or *sparry*, and the argillaceous or *lithoïd*; the former occurring in beds and pockets, in the primary rocks,—the latter in the newer formations, and especially stratified among the coal measures. The facility with which the former can be reduced, rendered it of abundant introduction in the smelting houses of the ancients; it was from this ore, that the Styrian works turned out the metal so favourably known before our era as the *Norican* iron; and the name of *steel ore*, under which it has been designated by some, from the readiness with which it furnishes a *steel* at the first treatment, is not less a test of its value.

But the other variety, *argillaceous iron ore*, the *fer carbonaté lithoïde* of the French mineralogists, is even

more valuable; not so much from the excellence of the metal produced, as from the cheapness with which the position and extractability of the ores allow an article, of sufficiently good quality, to obtain in general use and for a surprising variety of purposes. Its economy arises as well from the improved methods of manufacture now employed, as from its association with the beds of fuel for smelting it, and from their being in many cases actually taken out together. Indeed, these ores in Great Britain came only into use when, about one hundred years ago, pit-coal began to be employed instead of charcoal of wood; and in mining the coal, attention was also drawn to the ores which accompanied it.

They furnish now nearly the whole enormous product of Great Britain;—they are beginning to be used in France, where, as in the departments of the Nord, Loire, and Allier, they exist in abundance;—they return a small part of the metal from the Harz;—they are profitably employed to some extent in the bituminous coal fields of Pennsylvania, Ohio, and Virginia, in America; and finally, they are now lately worked with good success in this State, in the Allegany coal field about to be approached by the Chesapeake and Ohio canal.

I had purposed to present here a comparative view, derived from my own observation, aided by those of others, of the positions of this ore in Eng-

land and in America, and the methods of extraction in the former country; but fully to explain it, would require a more systematic and voluminous work than can be expected now. The following general remarks may suffice.

The principal iron districts in England are Glamorgan and Monmouth in Wales, the neighborhoods of Dudley and Bilston in Staffordshire, and the vicinity of Glasgow in Scotland. In the first district, that of Wales, there are altogether *sixteen* beds in which the ore occurs and is worked,—either continuous in bands, or in balls that sometimes touch or lap over one another, but always appear to have a sort of stratification. The average thickness of all these beds, taken together, is about *eight* feet; and the proportion of the metal, about 33 per cent. of the ore. M. Dufrênoy estimates the extent of this basin at 935 square miles; which, however, is not all available, in consequence partly of the local circumstances of the ground, and partly from the dislocations, irregularities, and faults in the strata. Such is the case at Merthyr.

In the Staffordshire basin, the number of beds is greater, and I think also the quantity of iron; though from its great depth below the surface, it is not so easily availed of as the Welch ores. The total thickness of the seams that are or have been worked, may be taken at about *five* feet; and the proportion of metal about 30 per cent. of the ore,—it being in this respect inferior to the Welch basin.

The ores and general features of the Glasgow basin have in the last ten years become extensively known, principally from an account and description by Dr. Colquhoun, to which I refer;[6] and which has been copied from the Journal where it first appeared, in 1827-28, into several other scientific publications.

The number of beds in this field, that have been explored, is fourteen; making a total thickness of nearly *five* feet: and the average proportion of metal is rather less than 33 per cent. But some of the beds, to which the greatest resort is had, yield considerably more; as for instance *Mushet's black band*, as it is termed, gives 42 per cent. of iron.

In the coal-basin of George's creek, and Jennings' run, in Maryland, these ores occur in considerable quantity. At Lonaconing there are twenty-two beds, varying in thickness from two to twelve inches; some of the beds are in continuous bands, others in flattened nodules, built together as it were in some places, in others merely contiguous. The aggregate thickness of all the beds yet explored and approached by drift, (no shafts having been sunk below the level of the creek,) may be taken at *seven* feet, and the proportion of iron 34 per cent. of the ore.

The following table exhibits the results of various analyses, made on ores from different points of this basin:

[6] Brewster's Edinburgh Journal, vol. vii. p. 224.

Analysis of Iron-ores from Allegany County, Maryland.

	*	*	†	†	†	†	†	†	‡	‡	‖	¶	¶
Protox. of Iron,	45.	42.	51.43	57.86	46.28	45.	37.80	36.	39.63	46.45	46.	43.96	47.
Silica, . . .	15.	13.	6.40	8.	7.	7.60	12.	16.	17.	14.	19.	14.90	16.10
Alumina, . .	9.	4.	2.	4.	3.50	3.	3.50	25.	0.70	5.60	0.50		
Lime, . . .	1.	7.	2.24	2.24	1.79	2.80	1.18	0.28	1.49	trace	: :	1.29	trace
Magnesia, . .	: :	: :	5.20	8.30	5.40	5.	2.	: :	5.80	trace	: :	: :	: :
Carbonic acid,	27.5	26.	31.33	17.20	32.13	33.70	40.52	22.32	31.86	28.47	27.	27.95	28.80
Coaly matr., Water, Loss, &c.	2.5	8.	1.40	2.40	2.40	2.	2.	0.40	: :	: :	5.50	8.40	7.10
	100.	100.	100.	100.	98.50	99.10	99.	100.	96.48	94.52	98.	96.50	99.

* Tyson: Memoir of the Georges' Creek Basin: pp. 12, 13. The specimens were from the Lonaconing Works; where these and others are now smelted. Both are from bands. Sp. gr. 3.433 and 3.255 respectively.

† Chilton: Report of the Maryland Mining Company: p. 20.

The first and second, and especially the latter, appear to be carbonates, altered from having laid near the surface. These are frequently taken for Hæmatites or Hydrous Peroxides from their appearance. The analysis, however, shews their constitution. It is not stated whether these were nodular or in bands, nor are the specific gravities given.

‡ Silliman: Report to the New York and Maryland Coal and Iron Company, London, 1838: p. 88. These were *nodular* iron ores. Of the first, the sp. gravity was 3.40, and it lost by calcination 31.31 per cent. Of the second, the sp. gravity was 3.17, and it lost 29 per cent. by calcination. The traces of Lime and Magnesia are stated to have been of their carbonates.

‖ Ure: Report, &c. cited in last note: p. 54. The specimen was nodular, with a sp. gravity of 3.25. This analysis likewise gave 2 per cent. of Sulphate of lime. This quantity was so small that it was neglected in the text.

¶ Daniell: ubi supra, p. 56. The specimens are not said to be nodular or otherwise, nor is their sp. gravity given. There were traces of Manganese in both.

Under this class may also be mentioned the altered ores, occurring in the secondary regions near to and below Baltimore.

These ores occur in the form of 'nodules varying in size from a few inches to several feet in diameter. The composition of these nodules in many localities is gradually changed into the hydroxide of iron—the cavities are, however, often lined with crystals of pure carbonate of iron, approaching nearest to that form called *mixte* by Haüy.'[7]

7. Silicated Iron Ore.—The silicates of iron are not worked in America, nor in England, where there is even a prejudice against them. Nevertheless there are silicates of iron, in which the metal is in sufficient proportion, and its associates not too infusible upon proper admixture, to render the smelting of them profitable. 'Such are,' says M. Walter de Saint-Ange, 'ferruginous garnets, basalt charged with oxidulated iron, the silicated iron ore of Kupferrath, cronstedtite, and jasper.

'At the works of Ardon they already treat the chamoisite; which is green, very fusible, magnetic before and after roasting, and yielding 43 per cent. of excellent iron.

'At Lendersdorf they use the silicated iron ore of Kupferrath; and in the principality of Henneberg in the environs of Suhl, they treat a garnet, of a

[7] Trans. Maryland Acad. of Sc. vol. i. p. 104.

reddish brown colour and regular form. The iron produced from this last is of excellent quality.

'Basalt, garnet, and the common jasper, are especially fit for entering the service of Metallurgy, because of the abundance in which they are found in different countries. Volcanic basalt exists in considerable masses in the departments of Cantal, Puy de Dôme, etc.; in Scotland, Ireland, the Hebrides, and in Germany. Garnet is in abundance in Bohemia, Silesia, Hungary, Spain, Corsica, Italy, and in many places in France. Jasper occurs in the form of thick beds, sometimes of entire mountains; and is found in Sicily, Piedmont and Siberia—also in France, in the departments of Isère and the Higher Alps.'

Taking as the type of this class the *chamoisite* mentioned by M. Saint-Ange, occurring at Chamoisin in the Valais 'in thick and numerous beds, in a limestone mountain abounding in ammonites, and probably therefore belonging to the lias formation,' we have the following analysis by M. Berthier:

Protoxide of Iron,	50.5
Silica,	12.
Alumina,	6.6
Water and bitumen,	14.7
Carbonate of lime,	14.4
Carbonate of magnesia,	1.2
	99.4

shewing a considerable per centage of Iron.

Its specific gravity is 3 times that of water; and its strict chemical constitution is assumed to be, 1 atom of Silica and 2 atoms of Water combined with 2 atoms of Iron.

8. Titaniated Iron Ore.—I mention this because a variety has been worked with good success at the Harford furnace of Messrs. Patterson, in this State.

Besides this locality, it occurs at several other places; such as at Menaccan in Cornwall, in Brazil, where it is in great abundance, constituting mountains or very thick and extensive banks, at Arendal in Norway, at Egersund in Salzburg, etc. etc.

All these localities appear to present differing varieties; the proportions of titanic acid being from 20 to 57 per cent. of the mass. In the case of a specimen from Transylvania, Klaproth found 84 per cent. of titanic acid, when it ceased for metallurgic purposes to be an ore of iron. In another case, from Maisdon, Berthier found the titanic acid as low as 9 per cent.; it being replaced by 34 per cent. of silica, leaving 31 per cent. of metallic iron.

I omitted to mention before, that traces of titanium are sometimes met with in the lithoïd carbonates about Merthyr in Wales; where it is seen, either in crystals of the oxide, in the cavities of the balls of ore, or as pure crystallized titanium, in the hearth of the furnace. In the latter condition it occurs also in the Scottish furnaces.

I subjoin the analysis, by M. Berthier, of the ore of the Harford furnace.

Protoxide of iron, Peroxide do.	80
Titanic acid,	18
Gangue,	2
	100

I am told that, though it required careful management, the iron produced from it was of good quality and profitable.

As for the other combinations in which iron is found—the sulphurets, phosphates, arseniets, tungstates, columbates, and chromates, they are either useless because of the costliness of the separation, as in the first case, or, from the greater value of some of the associated substances, are worked for and applied to other purposes in the arts, as in the last named instance. So also the *franklinite* of New Jersey, although containing 46 per cent. of metallic iron, has only been serviceable for the extraction of zinc; to which purpose it was very successfully applied by M. Hassler, during the fabrication of the excellent brass which he caused to be prepared for our national weights and measures.

The subjoined table, exhibiting the ratio per cent. of *metallic* iron in the different classes I have named, as well as a recapitulation of those classes, will conclude all that is necessary to be said in this chapter.

Class.	Variety.	IRON. proportion in 100 pts.	Observers.	Remarks.
1. Native Iron, . . .	. . . . .	100.	Klaproth, . .	The iron was only 92.5 per 100: but the impurities may be considered accidental.
2. Meteoric Iron, . . .	. . . . .	93.95	. . . . .	Average of 5 analyses given by Dr. Thomson: vol. 1, p. 432.
3. Magnetic Iron Ore, .	. . . . .	72.40	. . . . .	Supposed to be in a state of purity. M. de S. Ange gives it from 80 to 90 per 100, which could not be, if it were protoxide only.
4. Specular Iron Ore, .	. . . . .	70.	. . . . .	Pure.
	Red Hæmatite, . . .	67.67	Thomson, . .	From Muirkirk in Ayrshire.
	Compact Red Iron Ore,	56.50	Berthier, . .	Mean of 3 analyses.
	Red Ochre, ...	40.53	do. . .	
5. Fib's Brown Hæmatite,	. . . . .	56.96	D'Aubuisson, .	Mean of 3 analyses.
or Hydrous Peroxide,	Compact Br. Hæmatite,	59.18	do.	Mean of 2 analyses.
	Oolitic, ...	44.45	Berthier, . .	
	Ætites, ...	54.97	D'Aubuisson, .	Mean of 2 analyses.
	Granular, ...	42.21	Berthier, . .	Mean of 9 analyses.
	Brown Ochre, . . .	45.85	D'Aubuisson: Berthier,	Mean.
		17.50	Berthier, . .	Mean of 5 analyses.
	Bog Iron Ore, . . .	29.54	Karsten, . .	Mean of 2 analyses.
6. Carbonate of Iron, .	Sparry Iron Ore, . .	44.91	Klaproth: Thomson,	Mean of 3 analyses, 2 of Germany; 1 of Eng'd.
	Lithoïd, ...	32.78	Colquhoun, .	Mean of 8 analyses, Scotland.
	do.	32.88	Berthier, . .	Mean of 14 analyses, France.
	do.	34.96	m. p. . . .	Mean of 13 analyses, Allegany County, Md.
7. Silicated Iron Ore, .	Chamoisite, ...	39.50	Berthier, . .	
8. Titaniated Iron Ore,	. . . . .	44.54	do. . .	Mean of 3 analyses.
	. . . . .	60.	do. . .	From Harford County, Maryland.

CHAPTER III.

Of the Means, Machinery, and Materials, employed in the Manufacture of Iron.

To GIVE an account of the various processes, gone through by the Iron which we see daily in its finished state, belongs to a more detailed and systematic work. It will be enough, as this chapter will be read chiefly by practical Iron-masters, to mention such points of similarity or difference as seemed to me important to be recognized between the Iron-works of America and Great Britain, and also between those of the different manufacturing Districts of Great Britain itself; and to present such statistical details as are supposed of interest to our own manufacturers, and may be taken as authentic.

The manufacture of Iron is so directly divided into two stages (each of considerable extent and involving its own peculiar processes,) that it dictates a similar division in any remarks on the general subject. What will be treated of here, then, will be the production of pig-iron or castings from the ore, i. e. the operations of the blast furnace: the second and subsequent processes for the conversion of this

product into malleable or bar-iron, i. e. the operations of the forge and mill, will form the matter of a future Report—not less interesting for the scientific, than for the practical, considerations which it involves.

Sec. 1. *Of Blast Furnaces generally—their Location, Construction, etc.*

A marked difference is seen in the position and circumstances of the Blast furnaces in Wales and Staffordshire, arising from the different physical and economic relations of the two districts. Amid the mountains of Wales, the furnaces almost without a single exception are built against a hill-side, which thus in fact forms one side of the stack: in the wide and extensive basin round about Dudley, they are with the same uniformity built singly, or in a row of two or three, on the plain. In the former, the materials are generally upon a level entirely above, or but little below the top of the stack, and hence descend to it; but in the latter, they have always to be raised up by machinery after having been delivered at the base of the furnace.

There is also a difference in the material used in the construction of the furnaces in these two districts: In Wales, *stone* being generally employed except for the lining or in-walls, for which (as well as in some instances lately for the hearth) *fire-brick* has been used;—in Staffordshire the greater facility of extraction of an excellent brick-clay, (which is either a

pure fire-clay, or one rendered more or less refractory by an association or admixture of that ingredient) has suggested the entire building to be made of brick. In a suite of three furnaces, under erection in October 1839, in the neighbourhood of Dudley, and which were the best designed and executed of any that I saw in that district, the hearth and in-walls, which were of fire-brick bedded as usual in fire-clay, were carried on simultaneously with the shell of the stack. It is to be expected also, that in Wales the use of this material, which has been very successfully applied thus far, will before long become general.

The shape of the stack also is different in the two districts. In Wales they are massive square truncated pyramids. In Staffordshire, they are conical chimneys, rising out of an oblong breast-work of masonry. In this latter district, too, they are uniformly built together; in Wales, in several cases, the bases even of the furnaces do not join.

The Staffordshire furnaces are also much less massive, and do not contain nearly the quantity of masonry with the Welch furnaces.—To make up for that they are much more bound together with iron. In Wales the ironing consists chiefly, if not exclusively, in bars of one and three-quarters to two inches square laid horizontally on the parallel sides of the stack,—the ends bearing an elliptical or circular clamp of cast iron, secured by a nut.

But in Staffordshire, although among the older furnaces this method may be still seen in practice, it is more usual to employ vertical bars, and secure them in their places by strong hoops of iron encircling the stack. These hoops are placed, in many instances, so near together as almost to hide the material of which the building is composed.

One instance only of avoiding in a great degree the necessity of all those costly iron fastenings came under my notice, in Derbyshire, at the works of the Butterley Company. There the joints of the several ranges of stone (of which the furnaces were built) instead of being horizontal, were at right angles to the battered face of the wall; and in the centre of the three visible sides, corners had been designedly turned: so that the whole work represented four distinct piers. The expansion of the in-walls had been enough to separate the piers about three and a half inches from one another; but as every thing had been calculated for this, there was no dislocation or crack elsewhere. In the plates accompanying this Report will be found a sketch, shewing the manner of building and position of the stones.

The general principles of construction of the interior of a furnace have been well recognized, since the last thirty years, and are the same every where: that is to say, the said interior consists of two cones attached base to base, and the lower and smaller one

inverted. But within this general principle, the proportions and sizes of these cones, and the collaterals by which they are united, are almost infinitely varied. Thus the total height of the stack (exclusive of the chimney) may be found to vary, in different localities, from 35 to 63 feet; the width of the boshes (corresponding to the junction of the bases of the two cones) will be from 7 feet to 20 feet: in many furnaces the portion from the boshes to the trundle-head is a frustum of a cone, in almost an equal number it is a parabolic spindle; the Welch hearths are principally square or oblong in the direction of the lateral tuyères, while those in Staffordshire are more frequently circular; finally there has even been an experiment tried, in which the hearth, or crucible properly so called, is entirely omitted, and the interior, when newly built, presents the same outline which is seen in furnaces that have been long at work, and have become scoured out and degraded. The success of this method is represented as having been good.

These differences in structure are principally arbitrary; but there is a point in which furnaces vary, which is not so much a matter of caprice,—namely, the angle of the boshes. This is observed to differ in almost every locality; and should, in theory, depend upon the fusibilities of the ores, or (in cases where the absolute fusibility is the same) upon the strength of the coal and the intensity of heat sup-

plied by it. If we suppose a very fusible mine reposing amid intense heat upon boshes which have a small angle with the horizon, or are comparatively flat,—there is danger that the point of liquefaction will arrive too soon, and the melting materials will unite with the matter of the boshes and either scour them away, or, by forming a new and not so fusible compound with some of their ingredients, will become fixed there, and thus choke up and perhaps chill the furnace. Therefore for fusible mines, or with a combustible of great strength, it is proper to have the boshes more steep; while with weak coals or a less fusible ore, they should be more flat, in order that the cementation or chemical union, which must to a certain extent precede liquefaction, may have full leisure to take place.

The same considerations appear to be applicable also to another circumstance,—the width of the trundle-head; which is in like manner found to vary much. Thus the ordinary diameter at this part is between 6 and 7 feet, for large furnaces; but the Derbyshire furnaces before mentioned have (at least a new one lately built) a diameter of 9 feet; and some furnaces in Wales have even carried this as high as 12 feet.

I must take occasion to mention here the apparatus employed for *charging*, at the Butterley Works; which indicated much ingenuity, and also is found to answer an excellent purpose. The railway upon

which the cars came to the trundle-head, was continued entirely across the mouth of the furnace; and because the intense heat, even there, would be sufficient to burn out in a short time any solid bars, the rails are for that portion (say 12 feet) made *hollow*, and a constant stream of water, brought from a neighbouring spring in the adjacent highlands, is made to flow through them. This water either runs to waste down the sides of the furnace, or is conducted to the boilers of the Engine. The charge is thrown in directly from the rail-road car, instead of being loaded first on a barrow; which is effected by a peculiar construction. The body of the car itself is a cylinder, about three and a half feet in diameter, of boiler-plate; the bottom, which is conical, (like the bottom of a Bristol porter-bottle) is moveable in a vertical sense by means of a rack in an upright shaft attached to the apex of the cone, and worked by a pinion, whose axle and crank-handle extend to the front of the car. I have endeavoured to make this more plain by a sketch, that will be found among the plates; in which the frame-work for the play of the rack and pinion, the wide cylinder, and the shape of the bottom, are all shown. It is presumed that from the materials sliding off in concentric circles, there is a much better distribution of them, and a remedy to the evil frequently seen when the charging is performed only by one door. It is also asserted that charged in this uniform man-

ner, the furnace admits a greater number of charges in a turn of twelve hours.

In this particular, the number of charges, there is great variety in different furnaces, and (although not so much as in America) at different times, with the same furnace. About thirty charges, per *turn*, is the most usual in Staffordshire, and thirty-six in Wales;—but they sometimes do not exceed twenty, and I have seen them go up to forty-eight,—the coke-barrow carrying 500 pounds. But this will be spoken of, when I come to treat of the materials employed and their method of employment.

From the nature of the ground about the Staffordshire furnaces, which is an extended plain, it follows that it is necessary to lift all the materials of the charges to the trundle-head of the furnace; and for this purpose, various machinery is employed. Generally, it is a small steam-engine specially applied to that use;—sometimes an ingenious application of water to a system of alternating buckets is made;—and more rarely still, the steam-engine, which creates the blast, serves also to raise the materials. In the best arrangement of the second kind of motive power, which I observed in Staffordshire, the water was first pumped up by the blast-engine to the top of the furnace, whence it flowed into a bucket, whose whole bottom was in fact a valve opening upwards. The size of the counterpoising basket containing the

charge, was so proportioned, that, as the water-bucket became full, it descended by its greater weight until it reached the base of the furnace, where was a reservoir in which a projecting cleet, striking against the valve of the bucket, forced it up, and thus discharged its contents. Thus emptied, the water-bucket became lighter than the ore-basket, which had been by this time discharged; and of course, whenever the latter was, by hand, set free from the parapet of the furnace, the former ascended. At the place I speak of, the system comprehended two water-buckets and four baskets; these performed their work in a very regular manner, and were quite sufficient to supply the furnace. A part of the water, pumped up by the engine, served to supply the water-tuyères. When a steam-engine is employed, if the incline is at all steep, (and it varies according to circumstances from 15° to 40°) the rails are generally *racked*, to increase the adhesion and spare the machinery. At an establishment, immediately on the Birmingham canal, where two furnaces were in activity, making 60 tons per week each, the Incline-engine was of six horses power. Of course, whatever be the inclination of ascent, the platform carrying the baskets of coke and mine, etc. is always horizontal; the weighing and filling of the baskets is all done below, and the Filler goes up on the platform with them, at the proper intervals of charging; which interval, at the

place and time I speak of, was every half-hour. In Wales, generally this trouble is entirely saved.

Very rarely in any Iron-manufacturing district[1] in England, is there sufficiently uniform supply of water, for motivating the blast. Therefore almost uniformly, that part of the work is performed by a large steam-engine; one end of whose working beam is attached to the piston-rod of a double-acting blast cylinder. The proportions of this apparatus vary according to the localities. Generally it may be said, that[2] a low-pressure condensing engine of 22 horses, is capable of forcing as much air as is consumed by a furnace, making 50 or 60 tons per week: this is about 3200 cubic feet per minute.

It appears to be found of profit, however, to have larger engines, and with them blow at the same time three or more furnaces and fineries. These engines are from 80 to 100 horses power; and the fineries are estimated to consume one-fifth of the air furnished. For the large furnace establishments, the average size of the blast-cylinder is about 8 feet in diameter, and 8 feet stroke;—the number of strokes about 15 per minute. If more work is to be temporarily performed by the blast-engine, the speed of

[1] I recollect but one case of water-power applied in Wales—at the Plymouth Works of Messrs. Hill & Co.; where four furnaces and four fineries are blown by four cylinders, each 5 feet in diameter and 6 feet stroke. The piston-rod makes about 18 strokes per minute.

[2] All the Engines that I remember are *condensing*; they are sometimes *high-pressure* condensing engines, however.

the piston is increased, and generally about in direct proportion to the number of furnaces to be alimented; thus at one establishment, where are three furnaces blown into from a cylinder 9 feet diameter and 8 feet stroke, and making 14 strokes per minute, *four* furnaces are sometimes fed by increasing the number of strokes to 18, per minute.

At another establishment, where there are *seven* high furnaces, very frequently all in blast at once, and seven fineries, there are no less than three engines for the blast, one of 90, one of 80, and another of 40 horses-power. The cylinder of the larger engine is 9½ feet in diameter and 8 feet stroke; and the piston makes about 13 strokes per minute. Each furnace (they are fifty feet high) is estimated to consume 3500 feet of air[3] per minute;—the fineries being supposed to consume one-fifth of the whole quantity of air furnished.

I am informed that in the furnaces about Glasgow, the diameter of the blast-cylinders is somewhat below the average I have given for the Welch and

[3] This is in round numbers; the exact calculation would give a little more. On the general assumption that the loss of air is about 5 per cent. of the contents of the cylinder, the formula of calculation is

$$Q = 1.9\ alv.$$

where Q = the quantity furnished per minute in cubic feet; a = the area of the piston; l = length of stroke (both in feet and fractions;) and v = number of strokes per minute. These strokes are full strokes, or *revolutions*.

Dr. Ure gives the proportionate consumption of the fineries at *one-eighth* of the whole quantity furnished. I think, with the waste and other circumstances that would be taken in account under a more delicate formula than I have given, it will be found nearer to what is stated in the text.

Staffordshire furnaces; the stroke however is not less, and the speed of the piston greater. Hence they work also at a greater pressure.

By comparing the working of several different establishments in Wales, it results as the average of that district (and not far from the truth in other districts I believe) that *one* horse-power (33,000 lbs. raised 1 foot high per minute) furnishes about 130 cubic feet of air per minute, and corresponds to the production of *two* tons per week.

The use of Regulators of this large quantity of air, in order to its issuing in a uniform stream through the tuyères, is universal. The shape and kind however are very different at different localities. M. Dufrênoy has already divided them into three kinds:

1. Air-chambers of constant capacity;
2. Air-chambers whose capacity varies with the ascent or descent of a piston;
3. Water-regulators; in which the capacity varies to a similar extent as in the last class, but in a converse manner.

The first class comprehends those most generally used throughout Wales: as to their dimensions and shape, however, it seems quite arbitrary. At one establishment it was a sphere of 19 feet in diameter;[4] at another place it was cylinder, with hemispherical terminations, whose length was 30 feet and

[4] At Decazeville in France, there is a similar one, of the enormous diameter of 24 feet.

diameter 16 feet. I have been able to find no rule among the Iron-masters for its proportions, except to make it as large as possible. In theory, the blast, under a pressure of two pounds, should be equalized by the capacity of the regulator being nearly nine times that of the blowing-cylinder,—the size of the airways being the same in both. In general, regulators are from twelve to fifteen times as capacious as the blowing-cylinder.

The second kind requires an air-chamber, whose capacity need not exceed that of the blast-cylinder. Not unfrequently they have two such chambers,—each cylindrical, and furnished with its own piston.

The last kind is generally seen in Staffordshire. The troughs or boxes are from 30 to 40 feet long,—and from 10 to 15 feet broad, and about as much high. The ill effects produced by an access of moisture to the furnace are only counteracted by peculiarities of the materials and great care in the working, which they apply in the district mentioned; and this sort of regulators cannot be recommended to general use.

From the Regulator, the blast passes into the furnace generally through two tuyères, on opposite sides; and not unfrequently in Staffordshire, through three. In this case, the hearth should be more oblong than usual. This is not contradicted in the fact of there being one establishment near Merthyr Tydvil, where a *circular* hearth is blown into by three tuyères. In

such a circular, or in a square hearth, the position of the tuyères is not of so much consequence; but in the hearths which are oblong in the direction of the tymp, the axes of the opposite tuyères are never in the same vertical plane; or, what is the same thing, the streams of air on the two sides are not in the same line; so that in effect, the blast is somewhat diagonal or towards the corner. The distance of the planes apart, or the amount by which the tuyères are out of line, varies from four to nine inches.

Also, according to the quality of the iron wished to be produced, (this is especially the case in Staffordshire) use is made of one or the other of the two tuyère-apertures, which are made in the same tuyère-arch; one about two feet above the other, in a furnace fifty feet high. The chemical action of this arrangement will be dwelt upon in another chapter.

The size of the nozzles to the tuyères, varies in different places from two to four and a half inches. This variety arises from the difference of opinion, which has of late years especially existed among the furnace-managers, as to the practical effect of the blast under different degrees of pressure. These opinions resolve themselves into two classes; one of which maintains that the increased *pressure*, or weight of the air driven in the furnace, produces a special effect,—the other, that the *quantity*, or volume of air at the atmospheric density, is the only thing to be considered in the combustion, and consequent work-

ing of the furnace. As is very natural, each side, or some individuals of either side, have appeared to think, that the maintenance of their own proper opinion involved a great and necessary difference from the opinion of all others. In the next chapter, which will be devoted to a consideration of the Chemical phenomena of Furnaces, the definitions of this subject will be more fully given.

Without further reference to theoretical opinions, it may be stated, that in fact, the pressure in the Staffordshire blast is not more than 1¾ pounds per square inch at a maximum:—in Wales, the average pressure is found to rise to 2⅛ pounds per square inch, though there are cases of 3 pounds: finally, in Scotland, the pressure of the blast at an average is not much below 3½ pounds, and in some cases has amounted to 4½ pounds, per square inch. But I am informed that in some of the establishments in the vicinity of Glasgow, they are now perceiving an advantage in diminishing this enormous density.

The employment of *water-tuyères* is very common, if not universal, both with Hot and Cold blast furnaces. These utensils, made originally of cast iron of considerable thickness, have been subsequently fabricated of wrought iron or boiler-plate, of copper, and of the mixture (not properly an *alloy*) which takes place between iron and copper, when exposed together to a high temperature. This mixture was at first forged; but it being found to be *red-short*, or

apt to break before great heat, it was subsequently cast. The impression seems warranted now, after all these trials, that cast-iron of small thickness will be found the most serviceable.

In the use of various apparatus for increasing the temperature of the blast, the furnaces of Great Britain are nearly, or quite, equally divided. There is not the same equality, in the preference shewn for different sorts of apparatus. The methods of heating by the trundle-head, which has been the most extensive in America, is not found in England to give a proportionate advantage, in the economy of fuel only; a greater advantage is therefore generally by preference availed of, by erecting special furnaces near to each tuyère-arch. This requires more fuel, but greatly enhances the productive effect of the blast. The *quality* of that productive effect is a consideration that I will treat of hereafter.

In regarding this subject, one thing has struck me, which however I do not give as the result of specific observations, but only as entitled to the force of an impression, viz: that in establishments consisting of several furnaces, where there is the apparatus for hot-blast, the proportion of furnaces *in activity*, at the same time, is greater than in establishments using exclusively cold-blast.

The nature of the blast also affects, in a greater or less degree, the *aspect* of the tuyères and of the

trundle-head. In the use of hot-blast, other circumstances remaining the same, the tuyère is more clear and bright. Likewise the flame from the trundle-head, during hot-blast, I have seen attain an elevation not short of 25 feet,—a height I do not recollect ever to have observed during cold-blast. Generally in furnaces of the latter kind, a tuyère somewhat obscure is preferred in making Foundry iron; while a very bright tuyère is supposed to indicate the working of forge-pig. But this depends in all probability more upon the *materials* employed than upon any thing else: for different furnace-managers will sometimes affirm different rules.

The buildings and sheds about the furnaces, though presenting different architectural effects, are in general for very uniform purposes. Top-houses or Bridge-houses are, in Staffordshire, rare; they can hardly be said to be common in Wales, to the extent to which we find them in America. The Cast-houses, however, much surpass ours in all regards. Against a stack of furnaces, they are most frequently built with their gable ends in front, and with the ridge pole in the direction of the tymp. Both in front and in the interior, they are often supported on cast-iron columns; and the girders, rafters, and roof, of metal. This gives them an appearance of great lightness and beauty; as will particularly strike an observer at Cyfarthfa. The

height from the floor to the ridge-pole is rarely less than thirty-five feet, except in small establishments; and no part of the roof seems to approach nearer than eighteen feet to the ground. The roof of the cast-house does not always abut against the stack; and in such a case, there is a pent-shed attached to the stack, at a greater height, which throws off the water that, during rains, would otherwise fall about the Tymp-arch.

Of course every variety, that caprice or convenience could dictate, may be expected and is met with, in the interior passages and arrangements about the stacks and cast-houses. The access to the tuyères, etc. in some, is extremely confined and difficult;—the tymp-arch however is generally spacious, so as to afford as much room for the workmen, and as great an access of cool air, as possible.

This ventilation is very necessary, on account of the temperature of this part of an English furnace; which is much above what is experienced in our American furnaces. The difference, in this regard, arises from the nature of the combustible employed, from the much larger mass on fire at once, and from the immense quantity of *cinder* or slag, which both the yield of the furnace and the peculiarities of the ore cause to be produced. An ordinary-sized stack furnishes about thirty tons of cinder per day.

In some places the cinder, as formed, is directed to run into iron cars, which are brought close to the

furnace, upon a small rail-road for that purpose. The cinder thus becomes moulded in blocks of great size, which are removed from the cars by means of a crane, whose block is fastened to a metal ring and staple, inserted in the mass while quite fluid, and afterwards broken out; and are then sometimes used to build walls, instead of stone. Their main recommendation, in this respect, is that they are obtained without quarrying. Usually the masses which have been thus removed, are broken up and applied to the repair of roads; in which the material answers an excellent purpose.

The pig-beds too, as part of the interior of a Cast-house, are, in contrast with those in the country, enormous: and in some works (as at Cyfarthfa) considerable ingenuity has been exercised, in their arrangement for non-interference. At the place just mentioned, it must be said that after all, one bed is in the open air. This will probably be shortly remedied.

As to the repairs, or replacement, of the tuyères and tymp, which have to be frequently executed during a campaign of five to seven years, the average duration of one blast throughout England,—they do not differ from the methods (much less frequently put in practice) in America, except in degree. If the access to the arch is at all convenient, a new tuyère is set completely in two

hours. The 'putting in a breast' of fire-clay, as an auxiliary to the tymp, wings, and dam-stone, is an operation somewhat longer, because they are interfered with by the cinder. Finally, the replacement of the tymp, which is always preceded by placing the furnace in train, and diminishing the charge of mine and flux, can rarely be effected in less than two turns, or twenty-four hours.

It becomes often desirable to repair a portion of the inwalls near the charging-plate,—an operation much dreaded, because other artisans are required than the furnace-men themselves, who always are competent and called on to execute the repairs before mentioned. For this purpose, the furnace is made to carry less burden, for forty-eight hours before the intended commencement of the operation. The periods of the charges are much more remote than ordinary; and thus the materials consumed, without replacement, sink to the proper level, where the repairs are to commence. I have never heard of a depth greater than nine feet: but presume this is by no means the utmost limit. Balls of fire-clay and common plastic clay mixed, are then thrown in upon the top of the materials to the depth of one foot and a half to two feet,—the blast is shut off, and the masons descend into the furnace, and execute the repairs with an expedition, that the great discomfort of their position much enhances. They will finish generally within the period of two turns, i. e. twenty-four hours.

Much caution has to be then used in supplying the materials; as much of the clay as can be removed is lifted out, and small charges, in which the combustible predominates, are at intervals supplied: the blast also must be increased gradually. The furnace may thus be brought into ordinary working train, in about thirty hours.

The stoppage of the blast, for greater or less intervals, is very common in England. All the repairs I have mentioned, require its suppression; and other considerations have prompted its being taken off at some establishments for twelve hours on Sunday. Unfortunately the use made of this benevolent leisure by the men themselves, and the irregularity it produces in the train of the furnace, contribute to defeat the intention of this laudable arrangement, and to prevent its general adoption.

A furnace may sometimes be tightened up to prevent access of air, and left without blast for a much longer period than has been just now referred to; and I have heard of an instance of a furnace thus stopped for fourteen days,—but returning, in fifty hours after the re-application of the blast, to her ordinary train. This is an extreme case, and perhaps the ordinary train was never very good: but generally it may be said, that the effect of or suppression of blast for three or four hours is, in a large furnace and well managed, not observable.

SEC. 2. *Cost of Construction and Permanence of Blast Furnaces, and their accessories.*

HAVING presented, in the preceding section, such details as seemed to me of chief interest, regarding the methods of construction and machinery employed in Blast-furnaces, I offer farther some statements as to the cost of said construction and machinery, the prices of labor applied to carrying on an establishment, the resulting expense for the metal produced, etc. etc.

The Staffordshire furnaces are, so far as I could get information, cheaper in their construction than in other parts of England. M. Dufrênoy gives 164,725, as the number of *bricks* (fire-brick and others) required for one stack and lining; but this is only for a small furnace, with boshes of twelve feet. For a large stack of fifty feet and upwards, and fourteen feet boshes, it takes 220,000 bricks:—or their place must be supplied with metal. Of this 220,000—about 5000 will be *fire-brick;* moulded of different shapes and sizes to fit different portions of the hearth and lining. Such fire-bricks cost from 2*s.* 6*d.* (60 cts.) to 3*s.* 6*d.* (84 cts.) a-piece.

The cost of all the brickwork and materials, except the iron hoops and binders, M. Dufrênoy also states as being, for two stacks connected at the base, £1800, or about $9000. The same remark as to the size, just now made, must also apply here.

Two years later than M. Dufrênoy, Dr. Ure has, in 1839, given the same statement—I presume upon the authority of the French observer, as to the Staffordshire furnaces: and he has also given a general estimate of the cost of erection of *three* Blast-furnaces and accessories; which I subjoin here. Such a Table is difficult to be made out very accurately—both because a part of the expenses vary with the localities or are arbitrary, and because those who have made experience of the details are naturally indifferent, if not averse, to their being communicated. So far as my inquiries were satisfactorily answered, I have reason to affirm the general correctness of this statement:—although in some particulars it may be erroneous.

Estimate of the average cost of erecting three Blast-furnaces.[1]

Building Expenses.	
Foundations:	$2,400
Masonry of hewn stones:	3,000
Common Bricklayers' work:	6,000
Lining and Hearth, etc. (of fire-brick): . .	5,700
Fire clay; for filling the joints:	400
Lime and Sand:	4,000
Cast-Iron	
Cast-iron pieces; such as dam-plates, tymp-plates, sows, etc. about 72 Tons: . .	5,700
Wrought-Iron.	
Binding-hoops, Keys, etc.; 15 Tons: . . .	1,500
Amount carried over, ...	$28,700

[1] For the convenience of even numbers, I have rated, in the reduction of this estimate, the pound sterling at *five* dollars of our currency. The three per cent. excess, above its actual value, will bring it near the truth.

Amount brought forward, ...	$28,700
Cost of Labor.	
Masons and Laborers:	5,400
Miscellaneous.	
Scaffolding:	240
Tools:	800
Cast-House or Shed:	2,400
Cost of ground:	12,000
Accessories.	
Blowing Machinery and 80 Horse Engine:	32,000
Inclined Railway for mounting charges: . .	600
Gallery for charging:	800
Steam-Engine House:	2,000
Chimneys, Boilers, etc.:	2,400
Roasting-kilns:	2,400
Coke-kilns:	4,000
Dwellings for Workmen:	4,000
Total Cost:	$97,740

This total gives for one furnace $32,580; but it must be borne in mind that the cost is lessened, both in labor and materials, by building several at the same time. Also it must be recollected that these expenses, though stated here in American money, would not be found, in America, to produce the same practical result,—but would differ more or less according to localities.

Having before spoken of the repairs, requisite about a furnace, done by the furnace-hands, I give here some statements shewing the number of men considered necessary at the principal establishments

in Wales and Staffordshire; together with their respective compensations.

The first is on the authority of M. Dufrênoy—as being actual, at a well conducted establishment near Pontypool, in the year 1823. This is given for comparison.

Table of Wages in Wales in the year 1823.

EMPLOYMENT.	Wages per ton of Forge-pig.		REMARKS.
	s. *d.*	*D.* *cts.*	
Keeper:	10	20	For foundry-iron the keepers get 28 cts. per ton.
Filler:	8	16	For foundry-iron the fillers receive 24 cts. per ton.
Cinder-filler: . . .	8	16	For foundry-iron the cinder-filler receives 20 cts. per ton.
Limestone-breaker: .	5	10	
Coker:	1 3	30	
Coke-hauler: . . .	3½	7	
Coke-filler: . . .	4½	9	
Mine-burner: . .	5½	11	
Engineer:	6	12	
Pig-weigher: . . .	2	4	
Plate-layer: . . .	2	4	
Bridge-stocker: . .	6	12	
Box-filler:	4	8	
Repairs and tools, etc.	2½	5	
	6 10	1 64	Foundry-iron: . $1 84

Besides these, there are some other workmen paid by the month: such as

Cinder-hauler:	£3 10 0	per month.
Limestone-hauler:	1 10 0	do.
Watchmen:	3 10 0	do.
Stickmen, and others whose employment is not named:	6 16 3	do.
	£15 6 3	

This amount is equivalent, on an average monthly yield of 240 tons, to 1*s.* 3½*d.*, or 31 cents per ton.

The following statement of wages, in 1839, was furnished me from an establishment in Staffordshire.

Table of Wages in Staffordshire in the year 1839.

EMPLOYMENT.	WAGES.			REMARKS.
	Per ton of Metal made.	Per Week.	Other-wise.	
	cts.	*d. cts.*	*cts.*	
Keeper:	22	. .	. .	House-rent and firing free.
Filler:	24	. .	. .	Do. do. pays his own helper.
Limestone-breaker:	. .	3 84	. .	
Mine-burner: . .	. .	. .	6	On the ton of raw-ore delivered him.
Bridge-stocker: .	. .	3 84	. .	
Coker:	. .	. .	2	On the sack (¼ ton) of coke furnished by him.
Engineer: . . .	. .	6 00	. .	
Cinder-filler: . .	. .	7 20	. .	Pays his own helpers.
Pig-weigher: . .	7	. .	. .	
Blacksmith: . .	. .	10 56	. .	Pays his own striker.

The other laborers employed will average about 2*s.* per day. The metal referred to in this table is all *foundry;* and a comparison of the two statements will shew the position of Staffordshire, as regards the price of labor. Although this district has especially felt, I believe, the appreciation of wages, which has been going on for five years past, and may be considered as quite equivalent to one per cent. per annum for the last sixteen years,—the wages of keepers and fillers are yet lower than they were in Wales in 1823.

For the Welsh furnaces generally, the following Table may be exhibited. The wages of the higher officers are rated upon three or more furnaces, to be managed or supplied.

Table of Wages in Wales in the year 1839.

EMPLOYMENT.	Per Month.	Per Day.	Otherwise.	REMARKS.
	Dolls. Cts.	*Dolls. Cts.*	*Dolls. Cts.*	
Underground Agent:	100 00	. . .	. . .	£250 per annum.
Furnace Managers:	57 60			
Engineer:	28 04			
Girl or Boy at Ash-pit of Engine:	. . .	24		
Storehouse-man:	17 28			
Stick-man:	17 28	. . .	. . .	One or more according to extent of works.
Keepers and Fillers: on Mine Iron:	. . .	. . .	33	Per ton of metal made: *bright.*
Do. do. do. do.	. . .	. . .	23	Per ton of metal made: *mottled and white.*
Do. do. Cinder Iron:	. . .	. . .	29	Per ton of metal made: *mottled.*
Do. do. do. do.	. . .	. . .	25	Per ton of metal made: *white.*
Filler's underhand—a boy or girl:	8 60			
Cinder-filler:	. . .	. . .	20	Per ton of metal made.
Cinder Hauling:	. . .	66	. . .	19*s.* per week of 7 days.
Moulders: from 48 cts.:	. . .	1 08		
Pig-weighers:	19 68			
Colliers:	. . .	. . .	46	Averaged per ton (2500 lbs. nearly) of coal raised.
Coker:	. . .	. . .	40	Per ton of metal: where coke is used exclusively.
Miners:	. . .	. . .	2 34	Averaged per ton of ore (2500 lbs. nearly): 60 cts. retained to cover loss.
Mine-burners:	. . .	56		
Raising Limestone:	. . .	. . .	16	Per ton of 2350 lbs. nearly.
Breaking Limestone:	. . .	. . .	7	Per ton of 2350 lbs. nearly.
Raising Sand:	. . .	56		
Raising Fire-clay:	. . .	. . .	1 08	Per ton of 2500 lbs. nearly.
Laborers about furnace helping Pig-weigher, etc.:	. . .	56		
Miscellaneous Workmen: as follows				
Mason:	. . .	84		
Smith:	. . .	72		
Carpenter:	. . .	84		
Brick-maker:	. . .	. . .	3 84	Per M.
Lime-burner:	. . .	. . .	2	Per barrel calcined.

I presume the following statement will be found to represent the average of the number of hands, employed about a single Blast-furnace, throughout Wales: viz.

Table shewing the Number of Persons, and their daily Wages, requisite for carrying on a single Furnace in Wales, in 1839.

WHERE EMPLOYED.	PERSONS EMPLOYED.		WAGES PER DAY.	
	Men.	Boys or Girls.	£. s. d.	Dols. Cts.
Mine-kilns:	1		2 4	56
		2	2	48
Coking-kilns:	2		4 8	1 12
		8	8	1 92
Hauling and filling (horse added):	1		5 3	1 26
		1	10	20
Breaking limestone:		2	1 8	40
Keepers:	2		12	2 88
Fillers:	2		12	2 88
		2	1	24
Cinder-fillers:	2		8	1 92
Hauling and tipping cinder:	1		2 9	66
Engineer:	1		3 6	84
		1	1	24
Pig-weigher:	1		2 9	66
Stickman:	1		2 5	58
Laborers:	4		9 4	2 24
	18	16	3 19 6	19 08

This is very nearly 8 shillings or $1.92 per ton, supposing the weekly yield to be 70 tons. It is exclusive of all charge for superintendence, wear and tear, and extra-labor in repairs, etc.

Compared with the force usually employed about the charcoal-furnaces in this country, the number of persons given above is large: nevertheless from the lowness of their wages combined with the greater product of the furnace, this item in the manufacture is much cheaper in England than I have ever known it in America.

SEC. 3. *Of the Materials used in Blast-furnaces, their methods of Extraction and Preparation, and their Cost.*

THE character, quantities, and prices of the different *materials* form an object of importance to be next observed. Upon this subject, several statements of other observers have been already made; in particular, those of MM. Dufrênoy, Beaumont, Coste, and Perdonnet, deserve to be mentioned. But it may be remarked, that the same difficulty, which was before mentioned as in the way of obtaining an accurate account of the expense of building even one establishment, holds here; and is even enhanced in the fact, that the books are hardly in any one place so rigidly kept as to present a precise detail of all the operations. For the proportions of some of the different substances, it is true, the average, through a long period, of the not very delicate methods of measurement, may be sufficient to give a tolerably correct view; but the number and wages and modes of payment of the working hands are so different in every establishment, as to render items under that head not much more than approximations; and any average of those items, it would be hardly fair to take. I shall nevertheless take occasion to give one or two statements in this regard also: which may be considered to be as authentic as the nature of the case allows. But it will be first desirable to present some considerations, as to the character and modes

of preparation of the different substances employed in the primitive manufacture of iron.

The richness of the ore of Wales has been already said to be about 33 per cent. of metallic iron,—that of Staffordshire only 30 per cent.; and the mean of Dr. Colquhoun's analyses give 32¾ for the Scotch ores. All these ores are the same lithoïd carbonate of iron; and its average constitution in the different districts being nearly the same, the proportions of Mine to metal produced may be considered as quite uniform,—viz: about three tons of raw mine, to produce one ton of iron of average quality. But the price varies, in Wales, from 7 shillings to 14 shillings per ton; in Staffordshire from 4 shillings to 12 shillings per ton, added to which must be the very general use of the Lancashire and Cumberland hæmatites, which cost (carriage included) from 20 shillings to 25 shillings per ton; and in Scotland it is between 4½ shillings and 6 shillings per ton.

The extraction of ore in Wales may be said to be universally by drifts. There are however some shafts; though of no great depth. In Scotland, at least in the Glasgow measures, the depth of the shafts (by which it is entirely worked) varies, according to the locality, from 200 to 500 feet.

In Staffordshire, the workable beds occur both above and below the main or ten-yard coal, as it is called, which is situate about 350 feet below the surface. In some places, nodules are extracted at a

depth of about 130 feet; but generally the first workable bed is found from 190 to 200 feet beneath the surface. A second is worked at a depth of 250 feet; and a third lies immediately beneath the main-coal. These depths are in the neighbourhood of Dudley. They will of course vary in other localities in the same field, on account of the dip and disturbances of the strata. Thus, near Bilston, the main or ten-yard coal is reached at a depth of 140 feet, instead of 350, as near Dudley.

The association of the ores with other substances more or less difficult to remove, will make of course a variation, according to circumstances, in the quantity which a workman can extract in a day. But a fair average, I think, may be taken throughout England and Wales, by estimating each miner at 200 tons per annum. The usual allowance in Wales is a *half-ton* per day on all the miners and mine-labourers, for the year round.

The *roasting* is an operation essentially necessary to be performed with all these ores; except that the small quantity of Lancashire ore is added in its crude state. The expense of this process varies according to whether the open air is the place of roasting in heaps, or whether small furnaces are erected to receive it. The former is the most usual in Staffordshire, the latter in Wales. The expense of roasting in clamps is hardly more than the coal which is consumed. This coal is laid down in large

pieces at the bottom, in a sort of flue arrangement, and allowed to project a considerable distance beyond what is to be the surface of the clamp;—the mine is then stratified with slack and small coal; and the coal at the bottom set fire to, in the direction of the prevailing wind. The clamps are generally about ten feet wide, twenty or thirty in length, and ten feet high; but they often surpass these dimensions, and within certain limits, there is reason to believe that an economy is found in the large dimensions of the piles. It takes usually in Staffordshire *one-fifth*, by weight, of *slack* coal to roast a given quantity of ore: if large coal is used, the proportion is one-eighth, and according to the strength of the coal, and the proportion of coaly matter in the mine itself, it may be still less; thus at the Lonaconing works in Maryland, where the same methods are pursued, the common proportion for small clamps is one-tenth, and for large ones, descends even to one-twentieth. The quantity used in the Welch roasting kilns does not exceed one-twentieth, and sometimes is one-thirtieth only; it is therefore, without estimating the interest in the erection of the kilns, cheaper. It is also cheaper, in that the ore is never fused in a kiln, as it is not unfrequently in a clamp. After the vitrification has taken place, the ore is as difficult to treat as if its water had been left in it.

The loss of weight, manifested in the mine by

this process, is from 25 to 40 per cent. I have even been told of 45 per cent. loss, in the case of some particular beds; in whose constitution was present, a larger proportion than ordinary of carbonic acid and water.

The flux universally used is *limestone;*—except in one or two establishments in Northumberland and Durham, where they employ *chalk*, as I am informed, in proportion nearly or quite similar to those of limestone. This proportion is, in almost every case, by weight one-third,—by volume one-half of the raw mine. Occasionally, to alter the quality of iron or the train of the furnace, a greater proportion is employed.

In Staffordshire, they work the immense calcareous deposites round about Dudley Castle. These appear to wrap round Dudley Castle Hill, and another hill, about two miles distant, called the Wren's Nest. They occur in two beds,—one ten yards, the other about fourteen yards thick; which beds are separated by measures, from thirty to forty yards in thickness, of calcareous matter and shale, containing many fossil shells, and especially, quantities of *trilobites*, some of them of great size. From the highly inclined position of the limestone strata, it has been worked at several different levels; in particular, a branch of the Birmingham Canal now passes almost under Dudley Castle, through an

old working. More recently, they have seen the advantage of more systematic mining; and now, most of the limestone is brought to light by means of shafts. Two such shafts, 330 to 350 feet deep, are worked by the same engine, in what was formerly the pleasure-ground of Dudley Castle. Portions of the limestone are magnesian, as appears from the structure, and as some of the iron-masters have practically discovered; so far however as I could judge from my own examinations, this characteristic belonged only to the imperfect beds between the main measures. The average cost of the limestone is about 9 shillings per ton. From the old workings, it may be still had for 6 shillings.

The limestone used in South Wales is taken from the calcareous deposites, underlaying the coal-measures. This forms part of what the English Geologists have called the *upper transition* limestone, as the beds about Dudley do of the *lower transition*. It occurs in beds from two to eight feet thick; but the entire measures, or assemblage of these beds, are of great depth. Its cost of extraction is 1½ shillings to 4 shillings per ton. There also occurs here beds of magnesian limestone.

In Derbyshire, there appears to be a smaller quantity of lime used than in the other districts;—the proportion, to that of the ore, being $\frac{28}{100}$ instead of $\frac{33}{100}$. That used at the Butterly Works has a fetid odour. The cost is small for extraction, but I regret to have

mislaid an exact memorandum, made at the time of my visit.

As to the patents, which have been taken out since the last twelve years, for mixing other alkaline materials as fluxes (such as *salt*, *potash*, etc.) they do not appear to have met with practical success. It is very possible, that in strict theory applied to special cases, such additions might be expected to be useful;—in the operation of refining with *charcoal*, there is hardly any doubt but that the potash exercises an influence in bettering the quality of the metal: but for the blast-furnaces, the disappearance of the small quantities of such chemical fluxes, in proportion to the vast mass of matters simultaneously acted on, and the additional trouble and expense attending their use, have been sufficient to forbid their adoption.

In regard to another material, universally used throughout Great Britain, in the manufacture of iron,—the *coal*, it will be sufficient for our present purpose to present a few memoranda as to the varieties in its constitution, cost of extraction, and the proportions in which it is practically applied. For any thing farther on this subject, the reader is referred to Mr. Holland's History and Description of Fossil Fuel, etc.; where may be found a full and interesting account of the coal formation throughout England and Wales; including, under this general

name, all the specialties which are regarded in the terms, coal *measures*, coal *fields*, and coal *basins*; the first of which is generally applied, in view of the order of succession, thickness, and other circumstances of interest in the economy of *mining*: the second to the surface, extent, and relations of the districts in which the coal is found, which pertains more to *political* economy: and the third is more proper in considerations derived from the inclination, curvature, and other *geological* incidents of the coal strata. Our object being solely a metallurgic view, I shall present first some tables of analyses, which will aid in any classification for the purposes of the iron-master,—omitting in those tables the details of the ultimate elements of the material, whose chief interest is for the chemical philosopher.

TABLE I. *Of the constitution of European Coals employed in Metallurgic operations; and which may be called* Fat Coals.

	Anzin.	Balayre.	Lasalle	Alais.	Rive de Gier.	Dour.
	1	2	3	4	5	6
Carbon:	71.5	58.5	50.6	68.	66.5	71.5
Ashes, etc.:	3.5	3.1	7.	10.4	2.	5.2
Volatile Matter: . . .	25.	38.4	42.4	21.6	31.5	23.3
	100.	100.	100.	100.	100.	100.
Specific Gravity: . . .	1.284	. .	. .	. .	1.280	1.270

	Wigan.	Glamorganshire.	Newcastle.	Do.	Do.	Staffordshire.
	7	8	9	10	11	12
Carbon:	52.6	77.7	76.	60.5	67.5	62.4
Ashes, etc.:	3.4	2.7	5.4	4.	2.5	3.5
Volatile matter: . . .	44.	19.6	18.6	35.5	30.	34.1
	100.	100.	100.	100.	100.	100.
Specific Gravity: . . .	1.277	1.310	1.340	. .	. .	. .

TABLE II. *Of the constitution of Coals employed for Metallurgic uses in different places in Europe; to which may be given the name of* Dry Coals.

	WALES.			SCOTLAND.			STAFFORDSHIRE.	DERBYSHIRE.		NETHERLANDS.		
	Dowlais.	Cyfarthfa.	Pen-y-darran.	Clyde.	Calder.	Monkland.	Tipton.	Butterly.	Codnor Park.	Mons.	Rolduc.	Swansea.
	1	2	3	4	5	6	7	8	9	10	11	12
Carbon:	79.5	78.4	76.8	64.4	51.	56.2	67.5	57.	51.5	85.	87.	88.
Ashes, etc.: . . .	3.	2.8	3.2	4.6	4.	1.4	2.5	3.	3.	2.3	2.7	3.4
Volatile Matter: .	17.5	18.8	20.	31.	45.	42.4	30.	40.	45.5	12.7	10.3	8.6
	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

TABLE III. *Of the constitution of* Dry Coals *in Maryland; which have been employed in, or are applicable to Metallurgic operations.*

	Lonaconing.	Do.	Do.	Do.	Frostburg.	Do.	Do.	Do.	Do.	Do.	Do.	Lehigh, Pa.	Do.
	1	2	3	4	5	6	7	8	9	10	11	12	13
Carbon: . .	85.	81.16	80.08	79.25	66.3	84.67	79.97	82.01	76.77	81.	91.67	90.1	86.
Ashes: . .					14.3		1.63	2.99	8.57	6.		2.5	6.
Volatile Matter:	15.	18.84	19.92	20.75	19.4	15.33	18.40	15.	14.66	13.	8.33	6.6	8.
	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	99.2	100.
Specific Gravity:	1.584	1.525	1.552	1.386	. . .	1.337	. . .	1.350	1.302	. . .	1.770	1.550	1.590

Analysis of *Fat Coals:*

Nos. 1—5 are from France, and their composition determined by M. Berthier. No. 1 has been inserted because, in spite of its theoretically excellent constitution, it is found to be of inferior usefulness for smelting. Nos. 2 and 3, besides their metallurgic value, furnish about 12 per cent. of gas.

No. 4 is from the mine of Rochebelle near Alais (Gard.) This furnishes, on the large scale, 55 to 60 per cent. of coke, of excellent quality. No. 5, from the mine of Grande-Croix, near Rive de Gier (Loire) also produces a superior coke.

No. 6 is from the neighbourhood of Mons in the Netherlands; and furnishes coke of superior quality.

No. 7 is the *cannel-coal* of Lancashire—so called, says Dr. Thomson, from the brilliant candle-like flame, which it gives out. Dr. Ure has given an analysis of another specimen, from the neighbourhood of Glasgow, which differs considerably from this. He makes it

Carbon:	72.22
Volatile matter: . .	27.78
	100.

The volatile matter he ascertained to consist of,

Oxygen:	21.05
Hydrogen:	3.93
Nitrogen:	2.80
	27.78

The proportion of ashes he has not stated.

No. 8 is only stated to have come from Glamorganshire. It is probably from some of the lower beds. The cinders are perfectly white; an indication of freedom from pyrites.

No. 9 is from Newcastle; but I hardly know that it is actually employed in any smelting establishment. It is given more as characteristic. Its ashes are white, and contain 30 per cent. of lime.

Nos. 10 and 11 are specimens collected by M. Dufrênoy; the first from the Birtly Iron-works, near Newcastle,—the second from the Tyne Iron-works. No. 12 is likewise by M. Dufrênoy, from the Apedale Works, near Newcastle-under-Lyne in Staffordshire. These three last are proved to be incapable of application to the manufacture of iron, unless previously coked.

All the analyses of this table were made by M. Berthier.

Analysis of *Dry coals:*

No. 1, from the Dowlais Works, is remarkable for 'being composed of two distinct portions,—one brilliant and separating in small cubes; the other dull, with a conchoidal fracture, and analogous to the cannel-coal:' these two kinds are not mixed in the mass, but form separate layers.

No. 2, from Cyfarthfa, exhibits the same difference in its component parts; but another arrangement,—the bright and dull portions being irregularly mixed. The dull portion seems to approach the nature of

anthracite; and it is said that, from the observation of this at Cyfarthfa, the hope was conceived of the successful employment of the *culm*, near Swansea.

No. 3 is in structure approaching the Cyfarthfa; only, the two portions are not so intimately mixed. All these three kinds admit of being used *raw with cold blast.*

In regard to Nos. 4—9, no other remark is necessary, except that they are only capable of being used *raw when the hot-blast is employed.*

No. 10, 11, and 12, are of the nature of anthracites. No. 12 is in fact the culm, which is employed in part, at the Yniscedwin Works of Mr. Crane near Swansea; and in which much interest has been felt by the Pennsylvania iron-masters.

Dry coals in Maryland:

No. 1—4 are from the analysis of Mr. Tyson, of the coals used at the Lonaconing Iron-works in this state. No. 4 is of a large bed, fourteen feet thick; and in its physical character, strongly resembles the Dowlais coal just mentioned,—chemically, it more resembles the Pen-y-darran coal. All these coals are used *raw with hot, or cold blast.*

No. 5 is furnished from a mine near Frostburg. The analysis is by Professor Daniell.

No. 6, from the same neighbourhood, is the analysis of Dr. Ure.

No. 7, from the same region, was analysed by Mr. David Mushet.

Nos. 8 and 9 are from Professor Silliman's report before quoted, page 108. No. 8 was taken from the so-called Hoffman mine, near Frostburg. The earthy matters in the ashes were found to be in these proportions: viz.

Peroxide of iron:	1.33
Silica:	1.
Alumina:	.33
Lime, and a trace of Magnesia: . .	.33
	2.99

No. 9 is from a three-feet bed, on Mr. Howell's estate. Some of the component parts of the ashes appear to have been in the following proportions:

Peroxide of iron:	1.42
Silica:	2.05
Alumina:	1.42
Lime, and a trace of Magnesia: . .	1.42

No. 10 is Professor Renwick's analysis of a specimen from the same bed.

No. 11 is an analysis, by Professor Silliman, of a specimen from the upper part of the same bed. I have never seen the locality; but the coal probably resembles physically the Dowlais and Lonaconing coals. The seam is said to be about two inches thick. It is a semi-anthracite; the hitherto-denominated cannel-coals containing a notable proportion of volatile matter, as may be seen in the No. 7 of table I., which is taken from Wigan. Also Dr. Thomson

gives another analysis of cannel-coal from the Lancashire basin, as follows:

Carbon:			64.72
Volatile matters,	Hydrogen: . .	21.56	35.28
	Oxygen: . . .	0.00	
	Azote: . . .	13.72	
			100.

And M. Karsten separates the constituents of cannel-coal, from Kilkenny in Ireland (where there are true *anthracites* also) as follows:

Carbon:	74.47
Ashes:	.50
Volatile matter: . .	25.01
	99.98

No. 12, which an analysis, by Mr. Vanuxem, of Lehigh coal, and No. 13, by M. Berthier, of coal from the same region, are given to conclude the series of *dry* coals:—which, commencing at a point in chemical constitution, where the oxygen predominates over the hydrogen among the volatile matters, and mechanically, when the coal first ceases to cake in burning, terminates in pure anthracite. I do not, of course, know if these coals have been ever employed in metallurgy; but I give them as representatives of the probable elements of the anthracite, which has lately, with success, been employed in the reduction of iron ores, near Pottsville in Pennsyl-

vania, and of whose more precise constitution I am not aware.

In regard to the applicability of different coals to the blast furnace, I have already distinguished, in the notes to the tables just given, such as are used raw, and those that require coking. From an inspection of their respective constitutions, the conclusion of M. Dufrênoy seems warranted, that:

1°. The coal employed *raw* in blast-furnaces, with *cold* blast, must be *dry*, and highly charged with carbon:

2°. Coal, which has a notable proportion of bitumen, may yet, if of the *dry* kind, be employed *raw*, but only with *hot* blast: and

3°. *Fat*, caking coal, and such as alters its shape and volume to any considerable extent by the application of heat, is incapable of being applied *raw*, under any temperature of blast hitherto produced.

Such is the importance of *coking*, in the respective kinds of coal. In its nature, this process is generally the driving off, or evaporizing, the greatest part of the volatile matters, along with which go also, in greater or less degree, the impurities which are associated with the coal. Its precise effect will be best shewn by the following table; which exhibits the analysis of several kinds of coke, prepared in different places in France on a large scale, for the use of blast furnaces.

Analysis of Coke, *prepared on a large scale for Blast-furnaces.*

	La Garre. 1	Bes-seges. 2	Le Treuil. 3	Rive de Gier. 4	Durban. 5	Mont-martre. 6	Luxem-bourg. 7	MEAN. 8
Carbon: . . .	85.8	82.4	82.	75.	71.5	64.	59.	74.2
Ashes: . . .	11.5	13.8	15.	21.5	23.5	28.	23.	19.5
Volatile matters:	2.7	3.8	3.	3.5	5.	8.	18.	6.3
	100.	100.	100.	100.	100.	100.	100.	100.

These analyses are made by M. Berthier; and the last column has been added, because it will be found to represent very nearly the average constitution of cokes prepared in quantity.

No. 4 is a coke from the coal of Rive de Gier, used in the iron-works of Lavoulte, in France. The analysis of the coal itself, from the same mine, is given under No. 5 of table I. on page 149. Also M. Landrin has given an analysis of the ashes of the same coal, as follows:

Water, oil, gas: . .	41.
Carbon:	52.
Oxide of iron: . .	2.2
Silica:	1.5
	96.7

These statements, taken in connexion, would enable us to trace the useful affinities of the carbon and other elements, through the different states of the combustible. A number of such analyses, carefully made, would without doubt aid in filling up several points, which are still undetermined, or not accounted for, in the Theory of blast furnaces.

Besides the inferences that flow from the preceding tabular statements and remarks, the following generalities on the nature and employment of coal, coked and uncoked, appear to me to be warranted by the experience of the English iron-works.

The calorific power, or heating effect of coke and coal, may be considered generally as equal to that of charcoal, which is itself in this regard about twice as efficient as wood: but the metallurgic effect, which is different from their absolute heating power (owing to the fact that coke, from its refractory nature, requires an excess of air, and therefore in the furnace burns to waste) may be stated, for the four substances as follows:

Equal volumes:—	Coal	:	Wood	::	5	: 1.
Equal weights:—	do.		do.	::	15	: 8.
Equal volumes:—	Coke	:	Charcoal	::	2	: 1.
Equal weights:—	do.		do.	::	10	: 17.

These proportions are, in fact, subject to considerable variations; both from the quality of the coal itself, and also from the methods and care taken in the coking. Thus:

At Plymouth, 6 tons coal yield 5 tons coke; or 83 per cent.
Pen-y-darran, 6720 lbs. do. 5400 lbs. do. or 80 per cent.
Dowlais, 720 lbs. do. 475 lbs. do. or 66 per cent.

But at the last mentioned locality, they devote but little care to the operation; otherwise the product would be more in accordance with the theoretical result, which, according to table II. p. 150, is about 82 per cent.

M. Karsten has given large and elaborate tables of the results of experiments, on small quantities of different kinds of coal. A short abstract may not be without interest.

Table shewing the quantity of Coke *produced from different kinds of* Coal *in Europe.*

LOCALITY.	CLASS.	Specific Gravity	Coke per 100.	REMARKS.
Silesia:	*Fat coal,*	1.296	69.3	Mean of 7 experiments.
" Hultschin,	do.	1.316	86.9	Maximum of 7 do.
" Czernitz,	do.	1.362	58.5	Minimum of 7 do.
Eschweiler,	do.	1.296	82.	Mean of 3 do.
Westphalia,	do.	1.287	82.9	Mean of 3 do.
Newcastle,	do.	1.256	68.5	
Silesia:	*Short coal.*	1.330	70.2	Mean of 9 do.
" Reine Louise,	(Houille maigre,)	1.332	88.4	Maximum of 9 do.
" Caroline,	do.	1.280	61.5	Minimum of 9 do.
Westphalia:	do.	1.319	83.6	Mean of 4 do.
" Hamburg,	do.	1.323	89.1	Maximum of 4 do.
" Louise,	do.	1.292	72.8	Minimum of 4 do.
Mons,	do.	1.306	88.	
Silesia:	*Dry coal.*	1.324	64.1	Mean of 8 do.
" Laure,	do.	1.304	70.	Maximum of 8 do.
" Theodore,	do.	1.294	58.5	Minimum of 8 do.
Kilkenny,	do.	1.423	69.8	
Westphalia,	*Anthracite.*	1.358	92.4	Mean of 3 do.
Bardenberg,	do.	1.336	94.9	Mean of 4 do.

Farther, the loss of weight in the carbonization of wood is, according to the experiments of Proust, Mushet, and Scopoli, from 75 to 80 per cent. MM. Allen and Pepys make it even 82 and 85 per cent. for some kinds of wood. The same loss in coal is from 25 to 40 per cent.

The radiating effect of coal and coke, M. Peclet considers as greater than that of wood: but in practice, the ashes of the coke, which are very refractory, require a higher temperature, and of course

the consumption of more of their associated carbon, for their fusion, than the ashes of wood.

The absolute *calorific* effect of coke is greater than that of any other substance; when sufficiently favoured by circumstances, such as large quantity and free access of air. It raises the temperature of an assay-furnace 10° p. higher than any other combustible.

These effects may probably be traced to its superior density; nearly proportionate to which, are the effects of coke of various specific gravities.

The specific gravity of good coke should be about that of water; it not unfrequently surpasses it.

For particular purposes, a *light* coke is sometimes the best; as where an extreme temperature is not required. The whole consumption of the combustible will be found, at the end of such an operation, less than if a more dense article, requiring more rapid combustion, had been used. But for high-furnaces (and this holds good, more and more in proportion to the greater heights of the furnaces, from the friability of light cokes under pressure) a dense hard coke—which has not suffered much change of shape, whose colour is an iron-grey or perhaps more nearly that of graphite, and whose lustre is more *silky* than semi-metallic,—is likely to be the best.

The aptitude of different coals for making good coke, seems to depend upon their chemical constitu-

tution; which is nevertheless recognizable, to a certain extent, in the physical character. Thus, if the proper degree of fusibility (or disposition to cake) depends upon the proportions of oxygen and hydrogen, and supposing that hydrogen communicates this fusibility (all which is warranted by the analyses),—then it appears that great lustre, but deficient hardness and elasticity, manifest the presence of this element: on the contrary, great lustre, an intensely black color, and much hardness, indicate the predominance of oxygen, associated with a large proportion of carbon. In general the lustre and color seem to belong more to the carbon; and the mechanical accidents, hardness, elasticity, etc. to the other bases.

Two methods are pursued in Great Britain for coking the coal;—the one in clamps in the open air, like those before mentioned under the head of ore-roasting; the other in ovens, constructed for the purpose, of various shapes, dimensions, and energies.

In Staffordshire, the first method is universal; and to the great care which is taken in that district, may be ascribed, in part, the acknowledged superiority of their *foundry* iron. The ground immediately around the furnace-stack is covered with low, loosely-built chimneys; around which the coals are piled in heaps somewhat conical—generally fifteen feet in diameter, and four feet high. Large coal is

laid at the bottom,—the smaller coals (to be coked) above; the fire is introduced by means of the chimney, and once started, the access of air is regulated by a covering of slack coal and coal ashes. Such a clamp, of which there will be thirty or forty in the same groupe, contains from 12 to 15 tons; the cokes can be drawn in about a week; and the average yield is not found above 60 per cent. The process is under the management of a person, who is aided by one helper (or at most one man and one boy-helper) and who receives 4*d.* (8 cents) per ton of coke made.

The cost of 1 ton of coke may then be made out thus:

1½ tons of coal at 7 shillings: . .	10*s.* 6*d.*
$\frac{1}{10}$ " of slack at 3 shillings: . .	3½
Labor:	4
	11*s.* 1½*d.*

or about $2.67 of American currency.

The cost of the bricks, etc. for the chimneys, is too minute to be separated, and is allowed for in the cost of the slack coal.

It should be remarked, that the Staffordshire iron-masters very rarely have any interest or concern in working the coal themselves: but purchase it from other proprietors or lessees. In Wales, on the contrary, the coal is almost always worked by the hands of the establishment.

In Wales, and Scotland, both of the methods spoken of are applied; only the details of the arrangement are not the same as those in Staffordshire. In Wales, instead of a conical heap, they make an oblong pile thirty-five or forty feet long, six or eight feet wide at the base, and four feet high. Sometimes, there are chimneys built in it: but often the draft is left to be produced by the arrangement of the lumps of coal. The pile, containing about thirty tons of coal, is fired in three or four places; and the operation is terminated in three or four days, in the neighbourhood of Merthyr. The different qualities of the coal of the Glamorgan basin in the two extremities, east and west, make a great difference also in their application to and result in coking. At the Varteg Works for instance, in Monmouthshire, the coal is of that class, which may be denominated *fat coal;* while at Merthyr, it is *dry:* further west, near Swansea, it is *anthracitic,* and what is found in Pembrokeshire is like our Pennsylvania anthracite. The product in coke, however, taking an average of the bituminous coals, I should think would be not less than 75 per cent.

The same methods which are here described, I have seen used at the Lonaconing Iron-works in this State. The yield of coke (which has been entirely made from the bed whose constitution is given under No. 4, table III.) is about 76 per cent.; and under favourable circumstances, the operation is concluded in four or five days.

In Scotland, they in part use the Staffordshire methods, and in part, ovens; the loss of weight is about 50 per cent.; and a clamp of twenty tons will be drawn on the eighth and ninth day. But the very general employment of hot-blast, with which the Scottish coals are applicable in their *raw* state, has contributed much to diminish the amount of coking done.

The average cost of coke, made in this manner, may thus be stated for the districts mentioned:

		s. d.	
Scotland: Glasgow;	2 tons coal:[1] . .	9	
	$\frac{1}{10}$ " slack: . . .	1¼	
	Labor:	4½	
			Dols. Cts.
	Cost of 1 ton of coke: .	9 5¾	or 2 27½
England: Staffordshire;	as before:	11 1½	or 2 67
Wales: Merthyr;	1⅛ tons coal: . .	5 4	
	$\frac{1}{10}$ " slack: . .	0½	
	Labor:	1¾	
		5 6¼	or 1 32½
Maryland: Lonaconing;	1.3 tons coal: . .	65 *Cts.*	
	$\frac{1}{10}$ " slack: . .	01½	
	Labor and carriage:	22½	—— 89

[1] The price of coal is put down at 4½ shillings per ton; which includes the cost of transportation. The actual working prices are, as I have been informed, as follow:

			s. d.	
Main coal:	6 feet thick, . .	10*d.* to 1		per ton.
Ell-coal:	3 do.	1 3		do.
Piedshaw:	3½ do.	1 3		do.
Splint:	4 do.	1 2		do.

The employment of ovens is considered more economical, in regard to the proportion of coke made, and it is probable also in the quality,—the oven-coke being somewhat more dense and hard than the clamp-coke. No particular, or even principal, plan seems to have been adopted in Wales, as to the shape of the oven; the only thing of importance being to obtain, by means of properly secured apertures,[2] such a control over the draft, as to increase or diminish it at pleasure, to apply it at any required point, or finally to exclude it altogether for a season.

I regret that I cannot present here an authentic account of the expenses and product from any establishment using ovens; whose result would admit of being compared, in product and cost, with those of a similar coal, coked in the open air. At an establishment in France (Le Creusôt), where the product of coke by weight is 49 per cent. of the coal employed, the cost of 1000 kilogrammes (which may be taken as 1 ton) of coke is stated as follows:

Coal:	12*f.* 53*c.*
Hauling:	92
Labor:	1 78
Interest on construction:	41

15*f.* 64*c.* or $3.14. of our money.

[2] A perfect closure of the apertures is of much economy. By the substitution of cast-iron shutters sliding in grooves, for others which simply closed on hinges, the product from the same coal has been practically found, at Decazeville, to be 49 per cent. instead of 40 per cent. which it was before.

This is much dearer than the cost given above for English and American furnaces.

In conclusion, it may be said that:

1°. The oven-coke can be made from slack, and otherwise cheaper or useless coals: the clamps require coal of size.

2°. The product has been found, from ovens, about 10 per cent. more, at the same establishment, using the same coals.

3°. The yield is more uniform from ovens; and not subject to those large discounts, which have sometimes to be suffered in the use of clamps, from their accidentally firing and being consumed entirely, during a high wind. It is not uncommon, in Wales, thus to lose 50 or 100 tons in one afternoon or night.

4°. The skill required in the management of ovens is more costly, or at least more difficult to be procured, than that requisite for clamps; and the labor of drawing greater: at least, in Great Britain and America.

5°. The quality of the coke made in ovens should be, in theory, better, because it is more dense and hard; but in practice, the coke of the open air is nevertheless preferred by furnace-managers. This preference is probably founded on the fact of coal of worse quality being generally employed in ovens, and also from the sulphur and other impurities being, in some cases, more readily and completely evapo-

rized, from exposure of a greater surface, in air. The few chemical analyses however, which have been made, do not tend to confirm this last hypothesis.

6°. Finally, it is probable that the preference of one or the other mode should be justified by the nature of the coal,—there being some coals, which will not coke at all, otherwise than in the open air.

Another material, of great importance in the manufacture of iron, is the *air*, which is injected into the furnace. The considerations attached to this particular, however, belong to the next chapter; where I propose to discuss some of the principal chemical phenomena of blast-furnaces. It may be stated here, that the air should be as *dry* as possible; and that the average constitution of the different minerals used in the furnace, requires for combustion, cementation, and fusion, an atmosphere somewhat more dense than the ordinary air we breathe. This excess of density will be, at a mean, equivalent to 3 inches of mercury, or 1½ pounds.

The whole quantity of air (by weight) admitted into the furnace, in any given time, say a day, is enormous; being nearly three times the weight of all the other materials together. Thus, in a furnace making 9 tons of iron per day, the weight of all the mineral materials charged in that time will be

about 61 tons: the weight of the air[3] will be in the same time (at 3500 cubic feet per minute) 171 tons: It takes therefore *nineteen* tons of air for *one* ton of iron. The cost of applying this, is the quotient of the annual charges for wear and tear of machinery, attendance, and fuel, divided by the number of tons made in the same period. In the usual accounts, this is included in the charge for interest and labor.

As a conclusion to these generalities, which it seemed necessary to preface in regard to the means applied in coke furnaces, I subjoin here a columnar statement of the average quantities and cost of the different materials, and of the labor, necessary about one ton of iron. This average has been deduced from the working of twenty-three furnaces in Wales, Staffordshire, and Scotland; which I either visited myself, or derived the information from unexceptionable sources;—for the hot-blast workings in Scotland I have taken the statement of M. Dufrênoy, published in 1837. Of these twenty-three furnaces, ten were making forge-pig, and the remainder foundry iron: and only three were using the hot-blast.

I have preferred to exhibit this average, rather the details from which I have deduced it, because it accords more with the general feeling, which I have found, among the Iron-workers, of aversion to hav-

[3] The weight of 100 cubic inches of atmospheric air, at 60° F. and 30 inches of the barometer, may be taken at 31 grains, very nearly; hence a cubic foot may be estimated at 0.0765 pounds avoirdupois.

ing what they consider their private affairs, laid before the public; though I bear cheerful testimony to the uniform politeness and accessibility, which were extended to me, both in England and America, during the inquiries preliminary to this Report. For my own part, however, I am far from thinking that the interests of the iron-masters would be disserved by a full publicity of their individual results; it is, after all, the necessities of the public which apportions the price of their manufacture; and that price, under the same existing necessities, would be upon a general average the same, whether it brought to the manufacturers a profit of 40 per cent. on the cost, or no profit at all. Under circumstances of ordinary prudence, in the selection of particular districts or particular sites, for the investment of capital in this manufacture, it is the skill and discretion with which it is conducted, that causes success or reverses; and it may well be a question, whether as much harm has not been done to the interest of those, who are still permanently successful, by an injudicious competition of capitalists entering upon a business which, for want of information, eventuated disastrously, as could possibly have accrued from any division of their profits among rivals, who, well informed upon all items, could calculate the event of every step before it was taken. An illustration of this may be found in the fact, that among the details in my possession, of ten furnaces making the same

quality of iron, the difference between the highest and the lowest is only £1 3*s.* 1*d.* (or $5.54,) a difference universally within the *profits* of the manufacture, and in point of fact, in the particular cases I allude to, atoned for by the different demands of the market in the two districts, in which the furnaces were situated. But I leave this subject, in order to present the statement spoken of.

Table shewing the averaged quantities and prices of the Materials together with the cost of Labor for one ton *of crude iron, requisite throughout Great Britain in the year* 1839.

MATERIALS AND LABOR.	Quantity in tons.	COST. £ s. d.	COST. $ cts.
Coal: inclusive of Engine:	5.054	1 2 1	5 30
Mine:	3.015	1 4 0	5 76
Limestone:	0.749	2 11	70
Labor and incidentals:	. . .	17 0	4 08
		3 6 0	15 84

It was not possible in every case, to procure the quantity of coal used in the engine, separate from that which was used in the furnace; and I have therefore united them in this statement. But in seven cases, where the distinction was made, the average was 0.936 tons of coal, costing 1*s.* 9½*d.* per ton of metal. This low price is in consequence of the slack[4] coal being in some cases applied, though not in all.

[4] This word *slack* has already been employed several times; and although its signification is doubtlessly well understood, it may be a matter of curiosity to some readers to know its origin. It is borrowed from the German *schlich*;

The labor and incidentals do not include wear and tear, or interest on the capital invested. I apprehend that 7*s.* additional, would cover the average of these last items; and the total cost therefore of a ton of iron, at the furnace, would be £3 13*s.* sterling, or $17.52 of our money.

Parallel with this statement of the furnaces of Great Britain, may be placed one, derived in a similar manner, touching the charcoal furnaces of Maryland.

Table shewing the averaged quantities and prices of the Materials and the cost of Labor for one ton *of crude iron, in Maryland in the year* 1839.

MATERIALS, ETC.	QUANTITIES.	COST.
Charcoal:	142 bushels.	$7 07
Ore:	2.45 tons.	9 37
Lime:	. . . .	75
Labor:	. . . .	3 83
Incidentals:	. . . .	2 90
		$23 92

I apprehend that the amount placed to incidentals will nearly, if not quite, cover wear and tear; but it cannot be supposed to bear any part of the interest on the capital invested. I am without particular information on this head, but presume that about two dollars per ton, would approach the average charge for this item.

which, literally meaning any semi-coherent mass that creeps or flows slowly, has been figuratively applied, in mining and metallurgy, to ore, coal, or lime in the state of minute reduction, or of powder. The *slacking* of lime, improperly written *slaking*, is an illustration of the same use of the word.

No quantity has been assigned to the *lime* in the table, because of the different sources from which it is obtained, and shape in which it is applied. Only three furnaces in Maryland use *limestone;* in quantities varying from seven-tenths to fourteen-tenths of a ton, per ton of pig-iron. The others, all employ *oyster-shells;* which is more convenient to their respective sites, and also furnishes a purer lime. Ten bushels of this article, costing 5 cents per bushel, is, I am informed, the dose for one ton of crude iron.

The quantities of *charcoal* consumed, having been stated to me in some instances, by the number of bushels, and in others, by the cords of wood producing or supposed to produce it, I have deduced the average volume by allowing the cord of wood, under ordinary circumstances, to produce 40 bushels of charcoal. In strict calculation, the cord ought to be equivalent to 57 bushels; but without the greatest care, under favourable circumstances, such a proportion is never attained. How far the average I have taken, accords with the results of the preparation of charcoal elsewhere, will be shewn in a table that I shall presently offer.

No definite information as to the *weight* of the charcoal, has been communicated to me; and circumstances did not allow me to institute the necessary experiments, which, to be worthy of confidence, would have required a certain degree of care, and

a disposition of time not in my power to bestow. I nevertheless have collected, from other sources, the means of arriving at a probable average; which I also combine in the following table.

Table shewing the number of bushels and pounds-weight of Charcoal produced by one cord of Wood, in various places in France and Germany.

LOCALITY.	Volume in bushels.	Weight in pounds.	Weight of 1 bushel deduced.
Nièvre:	31	480	15.48 lbs.
Audincourt: Wood split: . . .	41	623	15.20
" Wood round: . . .	36	559	15.53
Châtillon:	41	647	15.78
Pyrenees: average:	34	655	19.27
Niederbrunn: Oak:	56	871	15.55
Beech; large: . .	53	959	18.10
Beech; branches:	35	631	18.
Pine:	56	687	12.27
Pontgibaud: Oak:	40	847	21.17
Beech:	35	567	16.20
Alder:	39	480	12.30
Birch:	32	447	14.
Mean numbers deduced:	40.7	650.2	16.06

The results of this table will be found to agree very well with the conclusions of Karsten, as to the nearly uniform quantity of charcoal furnished, under suitable circumstances, from all kinds of wood, indifferently. Rumford had indeed come to the same opinion, but upon ill-founded premises: while the analysis of the chemists, which determined the woody fibre, after proper desiccation, to be identically the same substance in all trees, was held to be an operation not analogous to the carbonization of commerce

and metallurgy. Therefore a great discrepancy is still found, in the results of the analytic philosophers who have experimented upon the subject: as may be seen in the single example I shall take, of *oak*.

According to	Weight, per 100 parts of Wood, of Charcoal produced from Oak.
Rumford:	43.
Hielm:	30.
Karsten: slowly carbonized: . .	25.60
Karsten: rapidly carbonized: . .	16.54
Scopoli:	25.
Marcus Bull:	22.76
Mushet:	22.68
Proust:	19.
Allen and Pepys:	17.40
Allen and Pepys: same specimen after exposure to the air, one week:	20.27

The causes of this difference are to be found in the different circumstances of rapidity or slowness, and of degree of temperature, under which the experiments were conducted: an illustration of which may be found in the experiments of Karsten, before referred to, and an abstract of which I give below, in the hopes that it may prove useful to those, who have certainly an interest in making their wood produce as much charcoal as possible.

M. Karsten operated, for every kind of wood, upon both young and old timber—the difference between which is by no means regular, and in no case except pine, has amounted to 1 per cent. I have taken throughout only the *young* of the species.

Table shewing the weight of Charcoal furnished from different kinds of wood, in the experiments of M. Karsten.

DESIGNATION OF WOODS.	CHARCOAL PER 100 PTS.	
	By rapid carbonization.	By slow carbonization.
Oak:	16.54	25.60
Beech, (*fagus sylvatica*):	14.88	25.88
Hornbeam, (*carpinus betulus*):	13.12	25.22
Alder:	14.45	25.65
Birch:	13.05	25.05
Pitch-pine, (*pinus picea*):	14.25	25.25
White-pine, (*pinus abies*):	16.23	27.73
Pine, (*pinus sylvestris*):	15.52	26.07
Linden:	13.30	24.60

Chemically considered, Wood, after having been properly treated, so as to drive off the resins, etc. with which it is associated, and to leave only the *lignin*, or *woody fibre* properly so called, is a compound of carbon and water, or rather of oxygen and hydrogen in proportion to form water. The proportions of these substances may be taken at a mean;

Carbon:	51		Carbon: 50
Oxygen:	43	or still more generally;	Water: 50
Hydrogen:	6		
	100		100

but in the analysis, in consequence of some affinities not clearly understood (but which appear to arise from peculiar methods of aggregation,) in some species a part of the entire carbon will be taken up by the hydrogen, in others oxygen will go over to the carbon, and in others again they elect and associate indifferently.

During distillation, various products are formed; to several of which, particular names have been affixed: but they are not of interest to our present purpose. All that need be remarked is, that many of the volatile products are strongly attractive of carbon at high temperatures, and therefore it is proper for the metallurgist to evaporise them with as low a heat as possible, both because he thus saves fuel, and because in the residuum there will be found more charcoal.

I shall terminate these details upon charcoal, by giving the results of M. Berthier as to the woods of Pontgibaud, found in the table on page 173. The analysis was made by rapid calcination in a platimum crucible, and confirms the conclusion of M. Karsten already exhibited.

Table shewing the constitution of several Woods applied to Metallurgic uses, in the department of Puy-de-Dôme.

	Oak.	Beech.	Alder.	Birch.
Carbon:	17.1	13.7	15.2	13.7
Ashes:	.4		.3	.3
Volatile matter:	82.5	86.3	84.5	86.
	100.	100.	100.	100.

Although in regard to the *weight* of the bushel, the several instances in the table, (page 173,) appear to differ very sufficiently among themselves, yet the mean weights deduced may I think be safely relied on.

M. Landrin gives[s] several experiments made by himself on this matter, in different parts of France;

[s] Maitre de Forges: tom. i. p. 206.

their mean result for charcoal of oak is 14.64 pounds per bushel; and M. Walter[6] gives, as established and well recognized weights, per bushel:

	lbs.	lbs.
Charcoal of *Hard* woods:		
Beech, (butt and body): . .	20.8 to	22.4
Beech, (branches):	18.4	19.2
Oak, (butt and body): . . .	17.6	20.
Oak, (undergrowth): . . .	16.	16.8
Charcoal of *Soft* woods;[7]		
Average:	11.2	14.4
Charcoal of *Resinous* woods:		
Pine and Fir:	14.4	17.6
	16.4	18.4
Mean: . .		17.4

The mean of 17.4 and 14.64 is 16.02 pounds per bushel, a quantity but little differing from that already established.

I shall notice only one particular in regard to the weights of M. Walter, because it is of interest to the metallurgist in his operations, and at least should be borne in mind in any experiment to ascertain the weight of charcoal. This is, that the charcoal of this observer had been sometime in store, and was therefore heavier by the moisture which it attracts from the atmosphere. It is no doubt for this reason, that the computation and commerce in this article is

[6] Metallurg. de Fer: p. 38.

[7] The class of *soft* woods consists of the chesnut, the linden, the birch, the alder, the aspen, and the poplar.

always by volume, and not by weight. Otherwise, in buying by weight, the furnace-owner would both pay more, and obtain a worse article; inasmuch as the redundancy of moisture has to be all expelled, at the expense of heat in the furnace. But it must be said, that the greatest absorption takes place in the first twenty-four hours.

MM. Allen and Pepys found, that in this manner there was an increase in weight, at the end of a week, in

Charcoal from	Oak: . .	of 16.5 per 100.
	Beech: . .	16.3
	Fir: . . .	13.
	Mahogany: .	18.
	Box: . . .	14.
	Lignumvitæ:	9.6

It seems, however, that the absorbing effect is not according to any regular rule.

The average quantity of charcoal, employed in Maryland to make one ton of crude iron, may be taken then, in accordance with what precedes, at 2280.5 pounds, or generally 102 of charcoal for 100 of iron. This appears to be a small consumption, and it may be therefore not uninteresting to compare it with the consumption elsewhere.

M. Hassenfratz[a] has already collected extensive details on this subject, as it existed fifty years ago:

[a] Siderotechnie: tom. ii. p. 38.

the result of which may be briefly stated, as giving, on one hundred and twenty-two furnaces, in Styria, Siberia, Hungary, Sweden, Saxony, the Low-Countries, and France, a mean of 193 parts by weight of charcoal for 100 parts of crude iron. The lowest proportion he found in Styria and Carinthia, viz: 66 charcoal per cent. iron; and the highest in Hungary, where it was 549 charcoal per cent. iron. The average of the Swedish furnaces was 127 per cent.; and that of fourteen furnaces in France 150 per cent.

Since the introduction of the Hot-blast, a considerable economy of combustible has also taken place. M. Dufrênoy gives[9] as the consumption at

Riouperou, (Isère):	127	of charcoal per	100 iron.
Wasseralfingen, (Wurtemb.):	113	do.	100 iron.
Bachzimmern, (Bavaria):	81	do.	100 iron.
The mean of which is	107	do.	100 iron.

The consumption in Tuscany[10] is also very small; the minimum being . 89 of charcoal per 100 iron.
and the average . . 103.7 do. 100 iron.
At the furnace of Cecina, in the same State, (with *cold-air*,) it is . . 100 of charcoal per 100 iron.
At the furnace of Malapane in Silesia,[11] (with *hot air*,) the consumption is 171 of charcoal per 100 iron.

Excluding the data of M. Hassenfratz, except in regard to Sweden, where the results are still nearly the same, the mean of the other statements given

[9] Voyage Metallurgique: tom. i. p. 445, etc.
[10] Garella: Ann. des Mines: tom. xvi. p. 32.
[11] Chatelier: Ann. des Mines: tom. xvi. p. 102.

shew a proportion of charcoal of 105.6 (equal to 528 wood) per 100 of crude iron; which may be adopted as a general average, under all the modern improvements, throughout Europe and America.

The causes influencing the consumption of the combustible (of whatever kind) in Metallurgy, appear to be of two kinds, chemical and mechanical. Among the former may be mentioned as chief, the fusible association of the ores, which generally, (though not always) is connected with the per centage of metal in said ores; next, the character of the flux employed; and lastly, the kind of iron which is aimed at. But in this last particular, the state of our knowledge is not enough advanced to enable us to speak with precision.

The mechanical causes of greater or less consumption are principally, the section, and general shape, together with the height, of the stack and its chimney,—in short, whatever tends to promote the draft of the furnace. As to what regards the air itself blown in, and its temperature, the causes are of a mixed chemico-mechanical nature, and are very influential.

I shall conclude this subject by inserting a table prepared by M. Walter, as to the probable proportions of combustible for different classes of ores. If not accurate, it gives at least a basis for observation and induction.

Table shewing the probable consumption of Charcoal per 100 *of crude Iron, with Ores of different sorts.*

DENOMINATION.	Proportion of Metal per 100.	Charcoal consumed per 100 of Metal.
Fusible ores—yielding:	25 to 30	66 to 90
	30 to 35	90 to 110
	35 to 40	120 to 130
Ores of mean fusibility—yielding: .	30 to 40	110 to 140
	40 to 50	140 to 180
	50 to 60	180 to 210
Ores hardly fusible—yielding: . .	30 to 40	160 to 200
	40 to 50	210 to 250
	50 to 60	250 to 300

The manufacture of Iron with *coal*, has been but within the last year introduced in Maryland; and there is only one furnace (that at Lonaconing, before mentioned) applicable to this purpose. The result was one, I believe, of entire success, both as regards the facility and economy of the manufacture:—the quantity made in any given time almost trebling, and the actual cost falling notably below, the same items in the charcoal furnaces of this State. I do not however present any statement of particulars, inasmuch as I am informed that the company, under whose auspices the works have been established, do not consider even their present results, as an exhibit of the average capacity of the means and processes at their disposal.

CHAPTER IV.

Sec. 1. *Exemplifications of the General Chemical Theory of Blast Furnaces.*

The theory of the Metallurgy of Iron, is to present to the ores such substances as have an affinity for, and will combine with, all the elementary constituents of said ores, except the iron: and the problem generally to be solved, is the assemblage of these combining substances in such states and proportions, as will tend to their melting and uniting at the lowest point of temperature, and consequently with the least expense of fuel; in other words, to produce the most *fusible* compound. Thus, we offer to the ores in the blast-furnaces, the *lime*, whose solvent properties are well known;—thus, the *silica* and *alumina* of the ores, inert matters which sustain by themselves, without melting, the most intense heat, are made to contribute to an important part;—and even the melted metal itself, when separated on the hearth from its other associations, is found, at a particular temperature, to re-act upon the pasty mass of semi-combined matters above it. This temperature is always the lowest, consistent with fluidity.

Without entering into much detail as to the principles involved in this theory and manipulation, which appear to be practically understood by the furnace-managers generally in Great Britain and America, to a degree sufficient for their purposes, it yet is of importance enough to illustrate what has been just said, by two or three analytic and synthetic tabular statements, which I have been at the pains to make out, and which will be prefaced and followed by a few explanations and remarks.[1]

The materials supplied to the furnace are of two kinds,—*solid* and *gaseous:* and of the same kinds are the materials produced. The *gaseous* material

[1] I annex in this note, as a matter of curiosity, the expressions of Samuel Rogers (of whom I have spoken in the Introduction) on the same subject.

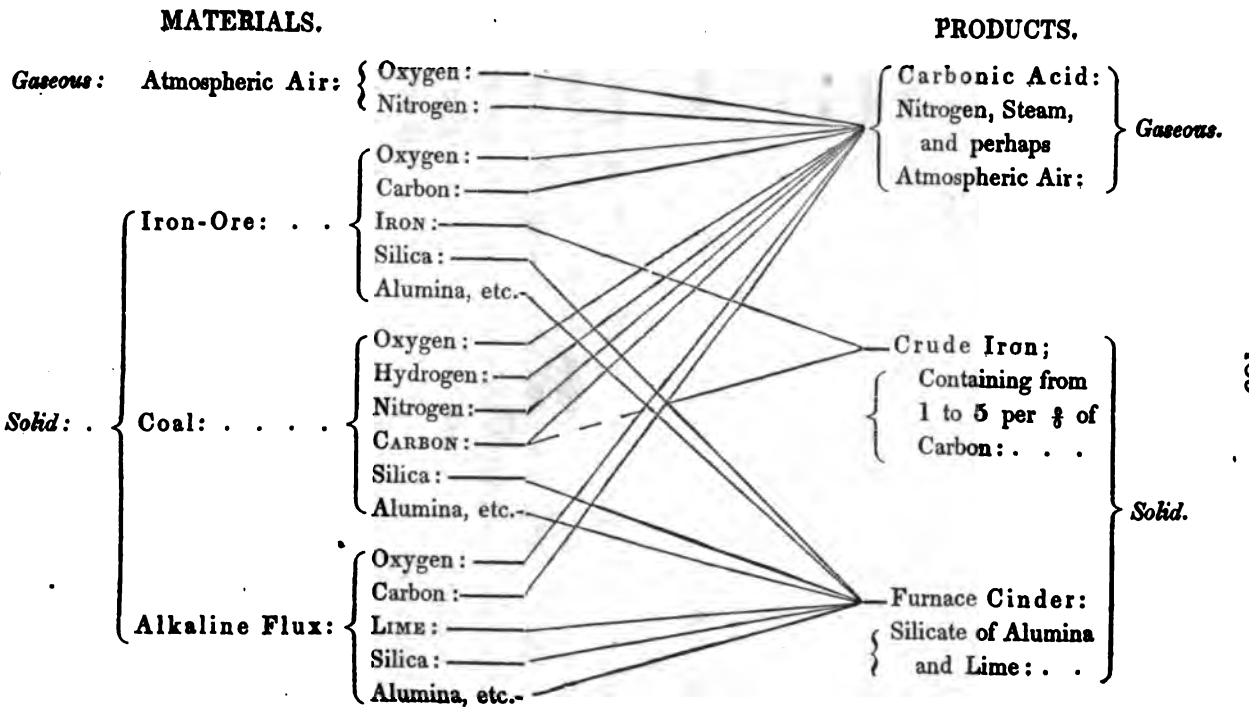
'The great desideratum,' says he, 'in iron making, is to separate all the elements combined with the iron in the ores or cinders, from which we wish to obtain the metal. These various elements are, all of them, perfectly different *insulated atoms*, which have the property of uniting and forming various compounds; and this inherent property is put into action, either by the pressure of the atmosphere, by magnetic influence, or some other natural though yet undiscovered cause,—assisted by caloric, light, and contiguity. This being the case, we have only to know what elements are to be acted upon, and withdrawn from their combination with the iron and with each other, to point out the additions necessary to *attract* all the various elements, by a more powerful affinity than that which unites them with the iron and with one another; producing new compounds, with the additions to effect this purpose.

'It is on this account,' he goes on further, 'that I so strongly recommend the complete and accurate analysis of the different materials employed in iron manufacture: for without such information, synthetical attempts to make good *iron* or good *furnace-cinder*, will always prove irregular and frequently abortive; and good materials be blamed from improper and random applications.' —*Letter* ii.

supplied, is atmospheric air;—the *solid* matters are, ores of iron, containing an oxide of this metal associated principally with silica and alumina; carbon, as it exists in wood or coal, together with a small proportion of the aforesaid earths; and an alkaline flux (lime), likewise combined with more or less earthy matters.

The resulting *solid* products are metallic iron, united with a very small proportion of carbon,—and furnace-cinder (as it is called) containing in varied combinations the lime, silica, and alumina. The *gaseous* products are carbonic acid, carbonic oxide, nitrogen, and water in the state of vapor; and perhaps atmospheric air, which has passed undecomposed through the furnace and escapes by the chimney.

However difficult it might be, *a priori*, to determine the course which the elementary constituents of the materials would take in order to form new compounds, after having been set free, by the action of caloric, from their aggregation in the old, yet when we have before us the new compound really resulting, we are able to infer with some certainty the respective directions of the different proximate or ultimate elements, and to define the agency of each material in forming the products. This has been attempted to be done, in the anagraph on the opposite page.


MATERIALS.
PRODUCTS.
Gaseous:
Atmospheric Air:
Oxygen:
Nitrogen:
Solid:
Iron-Ore:
Oxygen:
Carbon:
Iron:
Silica:
Alumina, etc.
Coal:
Oxygen:
Hydrogen:
Nitrogen:
Carbon:
Silica:
Alumina, etc.
Alkaline Flux:
Oxygen:
Carbon:
Lime:
Silica:
Alumina, etc.
Carbonic Acid:
Nitrogen, Steam,
and perhaps
Atmospheric Air:
Gaseous.
Crude Iron;
Containing from
1 to 5 per ℔ of
Carbon:
Furnace Cinder:
Silicate of Alumina
and Lime:
Solid.

In this sketch I have endeavoured, by the lines reaching from the side of Materials to that of Products, to shew the tendencies and affinities of the principal elements which are found in the substances used for producing iron; without meaning, however, to give in its place each specific element, or to affirm that each of the elements which I have given, takes precisely and in totality the direction I have assigned to it. Thus, in the iron-ore and in the limestone, there are ingredients such as magnesia, manganese, etc., very frequently met with, but not shewn here: nor am I prepared to affirm that the whole of the *nitrogen*, which is shewn as escaping with the carbonic acid, is actually got rid of in that way. The specifications are, however, minute and exact enough to serve as an illustration of the compositions and recompositions, which take place in the blast-furnace.

In order farther to shew the fecundity and extent of application of this theory, I shall next give some tables more detailed, and based in part upon actually existing cases; from which reference may readily be made to others, that are in a greater or less degree analogous.

The modern exemplifications of the Atomic system shew, that all bodies are chemically united in definite and permanent proportions; and that in their decompositions and fresh combinations, they are subject to general laws, which are, among other things, expressive of the habitual proportions in which their

elements tend to form new compounds. The precision of those laws, however they may diverge in any of the different annunciations of them from perfect accuracy, is yet sufficient, for any of the practical purposes to which there has been yet occasion to apply them. After this, the only thing arbitrary in the tables following, is the assumption that the temperature and other circumstances are appropriate for the various elements to exercise their natural affinities. I shall have occasion to point out, in the course of this chapter, certain cases, wherein, from a defect in those circumstances, the resulting affinities are not uniform with what might be anticipated from calculation. But these irregularities do not affect the principle of the present considerations.

On page 108, of this Report, is given an Ore (the first on the list), whose analysis and elementary constitution may be exhibited as follows:[a]

ANALYSIS.		ELEMENTARY CONSTITUENTS.		
Protoxide of Iron: . .	45.	Iron:	35. + Ox.	10.
Silica:	15.	Silicon:	7.5 + O.	7.5
Alumina:	9.	Aluminium:	5. + O.	4.
Lime:	1.	Calcium:	.7 + O.	0.3
Carbonic acid: . . .	27.5	Carbon:	7.5 + O.	20.
Coaly matter, etc.: . .	2.5	Carbon: 1.8 Hydrogen: .2	+ O.	0.3
	100.	=	57.9 +	42.1

[a] I have used, throughout this chapter, the system of atomic equivalents in which hydrogen is taken as unity; and as far as possible have employed

The immediate analysis of the Coal, which was used with this ore, is found on page 150, (Table III. No. 4); mediately it may be assumed:—

	Carbon:	76.90
	Oxygen: . . .	11.53
	Nitrogen: . . .	5.51
	Hydrogen: . . .	3.71
Ashes:	Silica:	1.
	Alumina: . . .	.58
	Lime:	.35
	Iron:	.42
		100.

It will not be necessary to exhibit the details of its elementary constitution; which will come in presently in the table, and which I have given for the ore only to shew the process of reduction.

The proximate constitution of the limestone, used for the Flux, is:—

Carbonic acid: . . .	34.7
Lime:	46.4
Silica:	8.2
Alumina:	8.1
Protoxide of Iron: . .	.4
Water, etc.:	2.2
	100.

whole numbers for the equivalents of the different elements. This, which in most cases is probably as near the truth as any other, both facilitates calculation and serves equally the illustration (all that I have aimed after) of the theory. So, for the same reasons, I have not carried the elementary proportions farther than the nearest tenth.

Also, the ordinary constitution of uncondensed Air may be taken to represent the elements furnished by the blast, (abstraction being made of the carbonic acid and the vapor of water), as follows:

Oxygen: . . .	23.
Nitrogen: . . .	77.
	100.

Such are the proportions of the substances, which have been introduced in the construction of the following table of composition. The caption of the columns of materials, is intended to shew the relative weights of the substances simultaneously acted on.

Table shewing the absolute elementary composition of the Materials *employed in a Blast-furnace using Coal.*

ELEMENTS.	ORE per 300 parts.	COAL per 260 parts.	FLUX per 100 parts.	Atmospheric AIR per 2000 pts.	TOTAL.
Oxygen: . .	126.3	33.	46.6	460.	665.9
Hydrogen: .	.6	9.7	.1	. . .	10.4
Nitrogen: .	.6	14.3	.1	1540.	1555.
Carbon: . .	27.9	200.	11.2	. . .	239.1
Silicon: . .	22.5	1.3	4.1	. . .	27.9
Calcium: . .	2.1	.6	33.1	. . .	35.8
Aluminium: .	15.	.8	4.5	. . .	20.3
Iron: . . .	105.	.3	.3	. . .	105.6
	300.	260.	100.	2000.	2660.

The *re-composition* of these elements, as stated in the column of totals, is exhibited in another table, derived from the constitution of the resulting products.

To construct this table, we may take the composi-

tion of the Iron, (regard being had only to its principal and most important associate—carbon) as follows:

Iron: . . .	97.75
Carbon: . .	2.25
	100.

The actual yield of metal, as furnished by the accounts of the establishment, for a certain period, was 34 per cent. of the ore consumed.

For the Cinder may be given these proportions, viz:

Silica:	37.2
Alumina:	22.7
Lime:	36.4
Protox. Iron:	3.7
	100.

neglecting, as has also been done in the analyses of the other cases, those ingredients which are frequently associated, but only in slight and varying proportions.

As, in the practical operation of an Establishment, there are no ordinary means of ascertaining the quantity of Cinder made, for our present purpose it it obvious that some measure must be assumed. From general observation I should suppose, that in any given period, there is about four times as much cinder run out as iron, while the relative specific gravity of the latter, in the present case, is very nearly 2.6 : 1 of the former; so that in round num-

bers, there would have to be one-half more in weight of cinder than iron, produced in the same time. Therefore in the caption to the proper column of the following table of re-composition, I have given the absolute quantity of Cinder 150 parts by weight, to every 102 parts of Iron. This also is supposed to harmonize, as to both products, with the captions of the preceding table.

Table shewing the absolute elementary composition of the Products *given from a Blast-furnace using Coal.*

ELEMENTS.	IRON per 102 parts.	Furnace CINDER per 150 parts.	GAS.					TOTAL.
			Steam.	Carbonic Acid.	Oxide of Carbon.	Carburetted Hydrogen	Nitrogen.	
Oxygen: .	. . .	59.8	235.5	192.9	247.7	. .	. . .	735.9
Hydrogen:	. . .	. . .	29.4	. . .	. . .	24.1	. . .	53.5
Nitrogen:	?	. . .	. . .	. . .	. . .	. .	1348.6	1348.6
Carbon: .	2.3	. . .	. . .	72.	185.6	72.2	. . .	332.1
Silicon: .	?	27.9	. . .	. . .	. . .	. .	. . .	27.9
Calcium: .	. . .	39.	. . .	. . .	. . .	. .	. . .	39.
Aluminium:	?	18.9	. . .	. . .	. . .	. .	. . .	18.9
IRON: . .	99.7	4.4	. . .	. . .	. . .	. .	. . .	104.1
	102.	150.	264.9	264.9	433.3	96.3	1348.6	2660.

A comparison of this table with the preceding one will shew, more fully than any verbal explanation, the views of the Combination-theory I am desirous to expose.

The coincidence of the *iron* in the two tables (the quantity produced being only 1½ per cent. less than the total quantity supplied in any manner,—a discount, that may well arise from discrepancies between

chemical analysis upon minute quantities and operations *in large*) is very satisfactory; that of the *cinder*, it is evident, depends upon the assumption of its volume being quadruple that of the metal produced. The different signs of the *aluminium* and *calcium* in the second table, one being too little, the other too much, proceed from causes that a more exact analysis will, I expect, remove. The component parts of the *gas*, which occupy five columns of this table, I have established upon the mean of eleven analyses by M. Ebelmen, of the gaseous product of a furnace using charcoal, with a mixture of coke. The quantity of *oxygen* is somewhat too great, and that of *nitrogen* too small; but as the object of the table is exemplification mainly, I have not thought it necessary to make the alterations in proportions, which otherwise might be justified by the analogies and circumstances of the analyses themselves. In another part of this chapter, I shall have occasion to recur to the subject of these columns, and treat it in more detail.

It is not to be doubted, that the managers of Iron establishments would find it much to their individual interest, as well as to the general advancement in the scale of public opinion of the important trade they support, in adopting a plan similar to what has been illustrated in these tables. I am far from asserting that the processes in the blast-furnace are of a nature

to allow, generally, the substitution of one chemical equivalent for another; or that equally good iron may be produced (by a certain arrangement and mixture of ores and fluxes) from all kinds of ore: but that much may be done in *improving* the quality of the metal from any given ore, by a due consideration and application of the principles I have pointed out, the result at one or two establishments in Great Britain abundantly shews. Nor is it, in fact, a necessary antecedent to the adoption of such methods that furnace-managers should become chemists; a degree of knowledge in that particular would be highly serviceable to them: but there are in America, and especially in Maryland, facilities for having thorough and extensive analyses made of the materials used at each establishment; while the tables I have given will serve to assist the determinations made from such analyses and may be used as patterns, to be improved and rendered more exact, for all analogous cases. The difference of effect between charcoal and coke, or coal, as a combustible, (although apparent in the constitution of the cinder) is not enough to present any difficulty in the way of calculating the affinities of the former, in the same manner as has been done for the latter.

Some metallurgists have endeavoured to determine the proportions of foreign and earthy substances, which are admissible in the constitution of

the ores, to be profitably worked; but no certain rule can be considered as established on this point. The following particulars, however, appear justified by the present state of our knowledge in this regard.

1°. Earths or ores, not containing more than 22 per cent. of iron, are hardly, if at all, worth working by themselves; not because the iron cannot be separated from its combinations, but because such separation will be attended with disproportionate cost. But if the other associates are in suitable proportions, such ores become exceedingly valuable as fluxes: so, at an establishment in France (having before satisfied themselves as to the suitability of its proportions) they fuse a *brown hæmatite* solely by the addition of a poor carbonate of iron.[3]

2°. Lime, alumina, silica and magnesia, earths frequently found in combination with iron-ores, may be considered as by themselves *infusible*. It is their union only, which allows of their being melted even at a high temperature.

3°. Even in this union, *silica* appears a necessary adjunct to effect fusion; as neither lime and alumina, alumina and magnesia, nor magnesia and lime are *per se* fusible.

4°. Although *silica* facilitates the fusion of any one of the other elements when mixed with it, and of the four mentioned, is only one that can be used *alone*, for the reduction of the oxides of iron,—its tendency is much increased, by uniting it with more

[3] Berthier: Voie-Sèche: tom. ii. p. 281.

than one. The mixture in suitable proportions of all the elements mentioned, (which makes a *quaternary* compound) is much more fusible than a mixture of any three of them; so, a ternary compound is more fusible than a binary one. An excess of silica, however, by combining with the carbon or with the iron or with both, produces white iron; and by rendering the cinder more refractory, is very apt to derange the furnace.

5°. Oxide of manganese also, often found in combination with ores of iron, is, when not in too large quantities, a valuable agent in promoting the fusion of any or all of these earths. When so found, it has sometimes rendered unnecessary the addition of any foreign flux. Its excess is accompanied by its being reduced along with the iron.

6°. Although in the ores generally used in Great Britain, and those in several places in Maryland, *lime* is a very suitable flux, it is not to be supposed that it is essential in every other case, or even in these.[4] In the instance alluded to in the last paragraph, the foreign flux dispensed with was *lime*.

[4] Karsten: Eisen-Metallurg. t. i. § 455, tran'd by Culmann: Metz, 1830. The application of lime as a flux to the iron-ores of coal-regions, has been shewn by M. Berthier (Ann. de Chimie et Phys. xxxiii. p. 154) to answer the purpose of taking up, *when in excess*, a portion of the *sulphur*, which is almost always found in those iron-ores. If the lime be however combined with silica in atomic proportions, its action is much weakened, or neutralized.

The limit to the application of lime in excess, is in the infusibility of the cinder after a certain point; which is on the one hand *equal quantities of oxygen in the two bases*, and on the other, *four times as much oxygen in the silica* as in the *lime*.

7°. When an addition of *silica* is required, it is effected to advantage by the use of matters, which with it contain also a portion of iron. It is thus that amphibole, basalt, and garnet have been applied.[5] This is in fact the use of a *poor* material, instead of one utterly sterile.

8°. In fine, M. Berthier[6] has concluded, from numerous experiments on a small scale, that of the whole solid materials introduced into the furnace (the iron excepted) the *silica* should bear a proportion of not less than 45 per ℔, nor more than 60 per ℔

Lime should be from . .	20	"	to	35	"
Other Bases. Alumina may be from	12	"	to	15	"
Other Bases. Magnesia, ...	12	"	to	25	"
Other Bases. Oxide of Manganese,	15	"	to	20	"
Other Bases. Oxide of Titanium,	15	"	to	20	"

But these numbers cannot be considered as universally applicable; inasmuch as I have myself observed a case, where the furnace was making excellent iron, and when the proportion of foreign matters was as follows:

Silica: . . .	39.
Lime: . . .	35.
Alumina: . .	26.
	100.

The other bases were in such small proportions, as not to be noted.

[5] M. Walter Saint-Ange: Metallurgie de Fer. p. 9.

[6] Voie-Sèche: tom. ii. p. 339.

SEC. 2. *Furnace-cinder; its Constitution and Phenomena.*

IT will illustrate what has been already said, to present here the results of some analyses of furnace-cinder.

Analysis of Furnace Cinder.

	CHARCOAL.							COKE.		
	PERROXIDES.			CARBONATES.				CARBONATES.		
	Mean.	Torgelow.	Taberg.	Pinsot.	S. Helene.	Ham.	Ham.	Dudley.	Dowlais.	
	1	2	3	4	5	6	7	8	9	10
Silica:	51.84	63.6	31.1	52.	71.	37.8	49.6	40.6	43.2	35.4
Lime:	21.80	24.	14.1	30.2	7.2	. .	. .	32.2	35.2	38.4
Magnesia:	4.82	1.2	34.2	5.2	5.2	8.6	15.2	. .	4.	1.5
Alumina:	15.21	3.8	8.9	5.	2.5	2.1	9.	16.8	12.	16.2
Protoxide of iron:	3.73	1.7	1.	1.6	5.	21.5	.4	10.4	4.2	1.2
Do. of manganese:	1.16	3.9	4.4	4.7	6.5	29.2	25.8	. .	. .	2.6
Oxide of titanium:	. .	. .	9.	. .	. .	. .	. .	. .	. .	. .
Sulphur:	. .	. .	. .	*trace*	. .	*trace*	.1	. .	. .	1.4
Phosphoric acid:	. .	*trace*	. .	. .	. .	. .	. .	. .	. .	. .
	98.56	98.2	102.7	98.7	97.4	99.2	100.1	100.	96.6	96.7

The numbers given in the first column of this table, represent the mean of ten analyses made by M. Berthier; nearly all the specimens for which, were procured at a time when the furnaces were working well. This column may therefore be taken as exhibiting the average constitution of good cinder, and consequently assists in determining the proportions of the earthy fluxes, which are to be supplied to a furnace.

No. 2 is from Torgelow in Pomerania; where the mine is much phosphated. The color is bluish-white; the texture rather of *enamel* than of glass. Its specific gravity was 2.62.

No one has yet suitably investigated the conditions, under which phosphoric acid exists in the high-furnace. M. Karsten is of opinion that it is all converted, becomes a *phosphuret*, and combines with the crude iron produced: but M. Berthier has signalized its presence, unconverted, in the cinder in this case.

No. 3, from the furnace of Ekersholm, at Taberg in Smoland, is remarkable for the large proportion of oxide of titanium contained in it. It is much tumefied, of a grey colour inside, more yellowish on the surface, and is not very fusible. The proportions both of limestone and silex might be increased to advantage.

No. 4, from the furnace of Pinsot (Isère), of a clear olive green colour and crystalline arrangement, is given because of its regularity of chemical constitution.

Nos. 5 and 6, the first from Savoy, the next from the County of La Mark, are given to shew how extremes in either way are indicative of the bad train of the furnace; which was the case when the specimens were furnished.

No. 7, from the same establishment with No. 6—only when the furnace was working well. The difference in the proportions of the protoxide of iron in the two instances, is very remarkable. This furnace is the one alluded to in the last section, where mention was made of no foreign flux being used;

and of the oxide of manganese, which exists in large quantity in their brown hematite, supplying the place entirely of lime.

No. 8 is from a well-going furnace near Dudley in Staffordshire, and was obtained by M. Dufrênoy.[7]

Nos. 9 and 10 were collected by the same philosopher, from the Dowlais Works in South Wales; the first (the furnace being in good train,) was compact, of a light grey colour, with glassy streaks of a deep bottle green, somewhat cavernous, and having the cavities lined with crystals. Its composition much resembles that of a specimen of *idocrase*[8] analysed by Klaproth. The other was when the furnace was in bad order, black, easily attacked by acids, with disengagement of sulphuretted hydrogen.

An inspection of the table will shew the difference before mentioned, between charcoal and coke cinder. In the former, the proportion of oxygen in the silica is nearly twice as great as in all the other bases:—in the latter, it hardly equals the quantity contained in the other bases. The compounds in the first, may therefore be considered as *bi-silicates:* in the other, simple *silicates*. Comparing this view of their constitution with the degrees of fusibility in the different states of saturation, and with the much greater heat generated in a coke than in a charcoal furnace, we may account for the difference—the *sili-*

[7] Voyage Metallurgique: tom. i. p. 340; Paris, 1837.

[8] Beudant: Mineralogie: tom. ii. p. 67; Paris, 1832.

cates, generally speaking, being less fusible than the *bi-silicates*—and these again more fusible than the ter-silicates. In regard to this, M. Karsten's remark is judicious; that 'in the reduction of iron-ores we should endeavour to form silicates fusible at the temperature employed; so that the fusion shall not be determined by too great a degree of heat, or by the vitrification of the protoxide of iron, which would be accompanied with considerable loss.'

The use of the cinder appears to be principally in four ways:

1°. As the ores are always associated with a greater or less amount of one or more of the infusible earthy matters which have been mentioned above, it would be impossible, in the greater number of cases, to separate the impurities from the iron otherwise than by fusion; or to fuse the material otherwise than by presenting to it fusible compounds in suitable proportions.

2°. The cinder in fusion, embracing and enveloping the iron, assists also in its reduction; first, by a greater communication of heat from a fluid surface, and secondly, by offering (as all *solutions* do) greater room for different affinities to act. It may be presumed, that this arises from the ultimate atoms being presented in a state of greater separation and distinctness.

3°. Some very fusible ores, such as the crystalline

or sparry carbonates, are apt to be *melted*, before the metallic compound is separated and reduced. The iron in such case, is mixed throughout the slag; and a proper addition of a refractory base is necessary to retard the fusion, until the deoxidation of the metal takes place: at which time, its gravity being much increased, it is allowed to settle at the bottom of the liquid mass.

4°. During the separation, which generally begins to take place just below the boshes, the metallic iron, in descending to the hearth, has to pass by the tuyères; through which, a large supply of atmospheric air is continually entering. The province of the cinder here, is to preserve the metal from contact with the air; by which it would be oxidated, and, if even it continued in fusion, would be materially deteriorated.

Hence the *degree of fusibility* of the cinder, is a point of much importance. If it be too thick and pasty, there will be difficulty in the iron making its way through: if it be too thin and liquid, there is danger of the metal leaving it too soon and being thus exposed to the current of air through the tuyères, or (if the liquidity be in a less degree) losing a portion of its carbon, and becoming more in the nature of *steel*. It is by an analogous process (though the shape of the furnace is very different) that some ores are made to yield malleable iron at once; as in the Catalan and Navarrese methods.

This subject, the fusibility of different alkaline, earthy, and metallic silicates,—which is one of much moment to the intelligent metallurgist, would draw me away too far from the main object of this Report, were it to be discussed at the length it deserves. I can therefore only give the order of fusibility of silica combined with several substances most usually met with; at the same time repeating the remark before made, that in proportion as the bases combined are more in number, the fusibility increases; so that two *infusible* silicates *per se*, may become *fusible* when presented together. As to this property according the different degrees of saturation of the silica with oxygen, it does not appear that a rule can be given applicable to all substances. For their simple combinations, they are arranged in their proper order, as follows:

Soda.
Potassa.
Manganese.
Lime.
Magnesia.
Alumina:—infusible *per se*.

The substances of this table, if taken two by two, or three by three, will generally in fusibility antecede the first named: thus a silicate of soda and potassa is more fusible than even a silicate of soda;—and a silicate of lime, magnesia, and alumina, comes in after manganese, although silica and lime are of very difficult and limited fusion together, and silica and alumina absolutely infusible.

Connected with the fusibility of the materials forming the cinder, in the furnace, is its *consistency* at the time of its flow, and its subsequent changes in this particular. A liquid cinder can only be produced by a considerable heat and fusible materials: but notice must be taken of its tendency to cool, before its indications can be taken as satisfactory. A rapidly cooling cinder shews the presence of metallic associations; and if its color be at the same time brown or black, it may be presumed that there is a notable proportion of iron, which has not been fully separated. In such case, therefore, the charges of mine should be diminished. A clear-colored cinder, liquid enough to flow over the dam-plate, and but slowly cooling, is generally desirable, as indicating good materials and a suitable temperature.

On the other hand, a thick pasty cinder, flowing with difficulty, argues the presence of infusible materials and a deficiency of heat. I have nevertheless seen a case of this kind, where the latter cause could not be supposed operative; and the derangement was attributed to too high a temperature. The cooling was slow, proving the absence of metallic mixtures; and the remedy was to increase the charge of mine. M. Karsten noticed a similar occurrence; though he does not mention the remedy.

In coke furnaces, a satisfactory indication is found in a cinder, liquid enough to flow slowly, but uniformly—cooling only after some exposure to the

air—and allowing itself, after the lapse of several minutes, to be drawn out into threads or twisted into various shapes, which it preserves against any thing but rough treatment. If the experiment of drawing and twisting be tried before it has cooled to a certain extent, the threads are apt to break spontaneously by irregular contraction.

The *color of the cinder*, and its other physical characters, offer generally, with the same furnace and the same materials, a test by which (in connexion with the character of the iron produced) the observant founder may, to a certain extent, judge of the processes which are producing it, and regulate his proportions and working accordingly. But there does not appear to be any general rule applicable to all cases, or any universal theory, which may serve as a standard for such a rule. An association of other metallic substances in the ores of iron, may affect, in an almost opposite amount, the color of the cinder produced; and in such an association, different effects upon the same characteristic, will be observed in coke and charcoal furnaces. Thus, in a *coke* furnace, an admixture of *lead* in the mine gives a yellow tinge to the cinder:[*] with the same admixture in a *charcoal* furnace, the cinder is a light grey.

In well-going coke furnaces, I have found the cinder chiefly of a whitish grey in the mass—with

[*] Karsten: Eisen-Metallurg: tom. ii. p. 240.

shades of blue on the outside, and streaks of blue, blueish green, and green, within. These varieties in color may be supposed principally dependant upon the reduction of minute portions of the metallic oxides, as manganese and iron; and upon the presence of a small quantity of phosphoric acid. It is only when the color has approached a *brown*, and through the intermediate shades to *black*, that there is reason to suppose a notable proportion of iron in the cinder; and the first remedy should be the diminution of the charge of mine. But to judge satisfactorily of the color, the cinder must be pulverized.

With the same materials, the greater opacity or translucency of the cinder, appears to depend on the combustible: with *coke* it is more opaque, with *charcoal* more translucent.

Among other physical characteristics, the cinder may be classed under the heads of *glassy*, *lithoïd* or stone-like, *earthy*, and *enamelled*.

The first indicates a greater fusibility of materials; and is generally found in furnaces which use charcoal, as the second is with those that employ coke. With the proper color and opacity, these are good indications for the respective combustibles. The *earthy* aspect of the cinder arises, I believe, mainly from a deficiency of heat; and not from a derangement of the furnace. Some of the founders in Wales

determine the application of the corrective for this, by the appearance of the iron which they are making. If it be well crystallized or granulated, they increase the quantity of air without apprehension; but if the iron be white and lamellar, the increase is made with caution. I am not prepared to say, that this is based upon any rigorous theory; for I have not found it universally the case. But I shall speak of this farther hereafter. A cavernous or honey-combed texture is a frequent accompaniment of this sort of cinder; and it may be supposed to proceed from a greater degree of the same cause, as well as from a less complete separation of the materials. The charges are generally, in this case, changed.

A cinder like *enamel*, is taken to indicate a deficiency of heat; but this aspect is not well recognized among the practical founders. Theoretically, it seems to prove both imperfect fusion and reduction.[10]

I have not thought it necessary to make a class of the cinder, containing (with a honey-combed or pumice-like texture,) small masses of earthy matters from the flux or the sides of the furnace, fragments of charcoal, or metallic grains. These occurrences prove, without controversy, a deranged state of working.

Such are the particularities and classification of the Cinder.

[10] M. Berthier attributes this characteristic, in part, to the presence of phosphate of lime. *Voie-Seche:* tom. ii. p. 341.

SEC. 3. *Characteristics and Constitution of the Metal produced, under various circumstances.*

THE other solid product of the Blast-furnace, is the metallic iron; to which the name of *crude* iron is with propriety applied. This consists principally of the elementary metal; associated chemically and mechanically with several of the other substances which have been introduced into the furnace, and which constitute, according to their amount and state of combination, greater or less degrees of impurity. So, the crude iron may be found to contain carbon, silicon, phosphorus, sulphur, arsenic, chromium, titanium, magnesium, aluminium and manganese—in very minute proportions; the first named of which, as it is found in greatest quantity, seems, too, in the present state of our knowledge, to exert the greatest influence over the product with which it is associated. Indeed, the nomenclature and classification of the crude iron is, up to this time, mainly regulated by the respective proportions of *carbon* mixed in it. At one time, it was supposed that *oxygen* was also a component part; but this, which remained as a fragment of the phlogistic theory, has not been recognized in the later researches of the most accurate chemists.

It still is to be regretted that these researches have not been carried to a sufficient extent, to furnish us with any complete and accurate theory of the

differences, readily discernible in specimens of different or of the same stages of manufacture; such as promised shortly to arise, when, in the latter part of the last century, the subject was illustrated by the philosophical labours of Monge, Vandermonde, and Berthollet.[11] But their conclusions, although to a considerable extent founded upon ideas which were technically *appropriate*, still did not embrace or account for several phenomena of manifest occurrence, and besides proceeded upon the admission (as in the case of oxygen just now mentioned) of some erroneous remains of the former notions; and it was reserved for Karsten, about the year 1816, to give a new impulse to the science of the Iron-manufacture, by the annunciation of certain observations which he had an opportunity of making, connecting, and to a great extent satisfactorily explaining, from the processes of the furnaces of Silesia, that were under his management. So, he was among the first metallurgists to show that the graphite (or *kish*) accompanying gray foundry iron, was *carbon* only,—occurring it is true among impurities, but not, as had been supposed, a *carburet of iron*; and following out the views which rested on this fact, he proceeded to explain and to confirm by analysis, the differences observable between the so-called *white* crude iron and *grey* crude iron, and thus to lay the foundation of appropriateness for subsequent additions or modi-

[11] Hist. de l'Academie des Sciences: 1786.

fications to his system. But it is not detracting from the well-earned reputation of this most practically learned man, to say that a good deal yet remains to be done to bring together some still not perfectly coherent parts of his theory, and by new and careful analyses to explore the operations and influences of agencies, which, in his published work at least, he does not seem to have taken in account. He, for instance, rather repudiates the doctrine of definite proportions, as it has been attempted to be developed in the first section of this chapter; and without adopting which, the science of metallurgy must continue to be retarded by the same causes, that had been operative for twenty years before the appearance of his first edition. Also, neither he nor any one since has yet examined with sufficient pains the electro-magnetic phenomena of Aggregation, Crystallization, and Aspect, which belong to the union, at certain temperatures, of iron with the various substances that may connect themselves with the metal during the process of reduction. In most other regards, his treatise may justly be considered as sustaining the base of the actual Theory of the Manufacture of Iron.

My present business being not to furnish a treatise on iron-making, but only to indicate, by way of Report, such observations as seemed to me principally worthy of being noticed by those who were concerned in the manufacture, I have hitherto studiously

abstained from long details: and its length already, exceeding and almost frustrating my intentions, warns me still more to study an intelligent brevity. I shall therefore not offer here any expositions of some yet incomplete inquiries and researches, upon the interesting topics which I have just now indicated; and shall only mention them again, when they come in connection with other and better established points, to which we shall find occasion to advert.

It is admitted that there is no part of the iron manufacture, upon which there is a greater want of consent, than in the classification and nomenclature of the different qualities of crude iron, produced in different establishments. Almost every furnace-manager has his own ideas, which, not referable to any generally established standard, are productive of this ill effect,—that they do not allow the observations and experiments, made with a view of its practical application to other purposes, to come under a strict analogy or unity. Hence, as one reason, we have as yet no uniform statement of its qualities in a very important particular, I mean its elasticity and resistance; points of great moment in its appliance to architecture of various kinds. But this can only be remedied in the extension of an accurate and general theory.

Under the names of *grey, mottled, bright,* and *white* iron, the founders generally include a wide

range of qualities for merchantable crude iron; but the distinctions are still farther removed from exactness, when, as is the case in several establishments in Great Britain, these classes are farther subdivided into No. 1, No. 2, etc. Some Works, professing (and it may be attaining) great uniformity in the main aspect of their metal, use only the latter mentioned terms of division. It is obvious that in this case the entire classification becomes of a local character.

It is probable that the characteristic differences may be all comprehended in two classes, *grey* and *white;* and that the other varieties observable, are dependant upon a mixture of these two qualities in the same specimen, or, what is the same thing, upon the alternate or irregular occurrence, during reduction, of the causes which would separately have produced grey and white iron respectively. I shall enumerate here some of the most important differences between these two kinds of iron.

Their *color* is a manifest distinction; from which indeed they derive their respective names. The first or *grey* iron, is of a grey color, more or less dark according to the texture, which is always crystalline and reflecting a brilliant light from the facets of which the surface is made up. These crystals, as seen under a microscope, belong to the Octahedral system; and present themselves under the primary forms of several of its classes. Their minuteness

renders their examination sufficiently tedious, and accurate conclusions concerning them slowly to be arrived at—their maximum limit being, when cubic, not above $\frac{1}{15000}$ of an inch in linear dimension, and about $\frac{1}{200,000,000}$ of a grain in weight. How far these are isomorphous with the ultimate molecules of the metal itself, remains to be determined.

The other,—*white* iron, is of a silvery white color, in general resembling the factitious metal called Argentan or German silver, and also affected by the texture. This, which to the naked eye appears lamellar, is in fact not less crystalline than in grey iron; only the crystals here are smaller, and seem to belong to the Rhombohedral system. They most frequently occur in six-sided prisms, sometimes connected in fascicles by their sides, at others by their ends, in a sort of stellated or radiating arrangement. The white color of the mass seems to be mainly arising from these arrangements of particles; as in the other kind, the *grey* hue is probably produced by the position and interference of the crystalline angles and facets. This is the more probable, since when under particular circumstances (which will be hereafter spoken of) white crude iron is converted into grey, and vice versâ, the color to a considerable extent is altered. It is not entirely changed in every case; and thus gives rise to a sub-division, which is known by the name of *granular white iron*. This has the same argentane color: but its

texture is an assemblage (like as in steel) of very minute Right Prismatic crystals, whose position produces on the light about the same effect with the laminæ of the type. A similar change produces similar phenomena, in the sudden conversion of grey crude iron into white iron.

The *specific gravity* of white iron is greater than that of grey. A specimen of white iron from Alais gave Dr. Schafhäutl a gravity of 7.582, that of water being 1.; while the highest that I know of for *grey* iron, is 7.300. This may be accounted for, in part, by the more compact aggregation of particles in the case of the former.

White iron is also *harder* than grey; and pieces are sometimes met, which cannot be scratched with the file. Grey crude iron is sometimes malleable to a very small extent; but the lamellar white iron, not at all. The granular white iron before spoken of, and which resembles very much the product called natural steel, has sometimes considerable malleability.

As to *extension* by weight or pressure, the phenomena respectively resemble those produced under the hammer. Grey cast iron is lengthened, before breaking, $\frac{1}{700}$ of its length, under a strain of 38,000 pounds per square inch: but white iron, hardly at all. So when the weight is applied transversely, grey iron will shew a deflection, from the level of supports three feet apart, as great as 0.84 inch, before breaking; white iron breaks as soon as it bends. It is therefore more brittle. It is also more stiff.

But, as might be expected, its *cohesive force* is less. That of grey iron, has been variously stated: by Rennie[12] at 19,072 pounds per square inch of section; by Brown[13] at 16,262 pounds per square inch, (these are the only *direct* observations;) by Tredgold,[14] on inference from transverse strains, at 44,620 pounds; and by Fairbairn and Hodgkinson[15] (the mean) 36,570 pounds per square inch. Nearly all the specimens in these cases, were of the second fusion. The continental observers are not much more accordant: but I do not include any of their results, because there is always a question of the relative weights and measures employed; otherwise in any special examination of the subject, they are entitled to at least equal consideration. In some experiments made by myself, the cohesive force of white iron, as deduced from the transverse strain, was found to be 34,830 pounds per square inch. The two classes, therefore, may be assumed as having a ratio of 35 : 40, in *respective* Cohesion.

In the force to resist *crushing*, however, white iron appears superior to grey. This kind of resistance, which may be called *relative* cohesion, in contradistinction to *absolute* cohesion (or resistance to a force tending to pull the material asunder) can only be considered reciprocal with the latter, when the

[12] Phil. Trans. 1818.

[13] Barlow: Strength of Materials: p. 205. Ed. 1837.

[14] Essay on Cast Iron; 2nd Ed. p. 84, seqq.

[15] Mech. Mag. May, 1839.

force applied is not great enough to produce permanent alteration. It is with this reservation, that the postulates and calculations of Mr. Tredgold are to be taken.

The experiments of Mr. George Rennie upon this subject, being made upon iron of the second fusion, are not applicable to our present purpose. I will only observe, that Mr. Tredgold deduces from the experiments the crushing weight of 93,000 pounds per square inch—my own calculations have furnished me the mean of 106,300 pounds.

M. Karsten has, however, experimented extensively upon this point, and with the same special view. Some of his results I present here. The quantities are the mean of several specimens.

	GREY-IRON.				WHITE-IRON.			
	Position when cast.		CRUSHING WEIGHT		Position when cast.		CRUSHING WEIGHT	
			Pr. sq. Millimet	Pr. sq. Inch Eng.			Pr. sq. Millimet	Pr. sq. Inch Eng.
			kil.	lb.			kil.	lb.
First fusion: . . .	Hor'l	. .	100.33	142327.6	Hor'l	. .	137.49	195580.
" " . . .	. .	Vert	103.38	147020.	. .	Vert	150.31	213761.
2d do. Cupola: . .	do.	. .	99.02	140819.8	. .	. .	. . .	. . .
" " . . .	. .	do.	97.76	139028.	. .	do.	124.49	177045.6
2d do Reverb'y Fur:	do.	. .	118.03	167854.6	. .	. .	. . .	. . .
" " . . .	. .	do.	123.69	175439.	. .	do.	179.89	255828.

Hence, white iron is more suitable for pedestals, short columns, and such objects as are required to bear great weights, in a uniformly perpendicular sense. A proportionate effect also, in different methods of treatment, appears to be indicated by these experiments. The difference between horizontal and vertical casting, was signalized too by

Mr. Rennie, during his experiments just now quoted upon absolute cohesion.

As to the *adhesion* (i. e. the measure of the force necessary to separate a solid and a liquid surface in contact) of iron, I know of no experiments since those of M. Guyton-Morveau; which placed iron in the *ninth* rank, and in which a weight of 115 French grains (friction excluded) were required to overcome the adhesion of a circular inch of this metal to a surface of mercury. *Gold*, under the same circumstances, required 446 grains. This subject appears worthy of consideration, in connection with the crystalline forms of crude iron.

In *capacity for heat*, white iron appears inferior to grey; it is therefore fusible at a lower temperature. But grey iron becomes more fluid, at the same temperature above its proper point of fusion; and takes longer time in cooling. Accordingly it is recognized as the most suitable for fine castings; because it fills more thoroughly all the small cavities of the mould, and is longer subject to the hydrostatic pressure in pouring. The precise points of fusion, however, have not been ascertained. [16]

[16] The fusion of cast iron has been usually stated at 130° of Wedgwood's pyrometer, equivalent in the assumed scale to 17977° Fahr. But the uncertainty of the indications by this method are well known.

M. Clement-Desormes inferred, from comparison with the liquefaction of ice, the melting point of cast-iron to be 3164° Fahr. Mr. Daniell, in experiments with his black-lead Register-pyrometer, found the same point at 3479° Fahr.; but subsequently stated it as more probably about 2786° Fahr.—*Phil. Trans.* 1830, *pp.* 260, 261. 1831, *p.* 452.

The mass of both kinds occupies less space in fusion than when yet solid at high temperatures.[17] Hence an allowance (generally one-eighth of an inch per foot) has to be made in the dimensions of the patterns, from which objects are required to be moulded and cast. But the dilatation in becoming solid, is less with white iron than with grey. In the former, it rarely reaches $\frac{1}{95}$ in linear measure; in the latter, it is sometimes $\frac{1}{98}$ in each of the three dimensions. Analogous differences hold good in the bar-iron, manufactured from the different kinds respectively;—a circumstance, which does not appear to have been yet taken into account in the experiments on the expansion of this metal by heat.

Such are the principal physical characteristics of these two kinds of crude iron.

Their chemical differences are much less easily detected; some of the elements (as for instance, the *altered carbon* in white cast iron) being very difficult of precise separation.

Nor have chemists, until comparatively of late times, applied themselves to the analysis of this sub-

17 This anomaly (for the general law of heat is to expand proportionately all bodies in which it is introduced) seems to be owing to the crystallization of the particles, upon the cooling of the mass. The same effect is observable in water; which occupies more space at 32° F. (when crystals commence to be formed) than at a higher temperature of 39½° F. Some other substances, likewise thermo-crystalline, exhibit the same phenomena; such are sulphur, antimony, zinc, and bismuth.

stance, the extent and value of whose practical use do not, fortunately, depend upon an exact acquaintance with its chemical constitution.

I shall present here some analyses of crude iron, from M. Berthier and M. Karsten; in which only the proportions of the impurities are given.

Table shewing the elementary associations of different specimens of Crude iron; *in parts per cent. of the Mass.*

	White-Iron.					Grey-Iron.				
	charcoal.					charcoal.			coke.	
	Lekeberg. 1	S. Dizier. 2	Tredion. 3	Lohe. 4	Hamm 5	Hamm 6	Torgelow. 7	Perts. 8	Charlerol. 9	Staffords. 10
Carbon: . .	3.9	3.6	3.6	3.5	5.1	4.4	2.6	1.9	2.3	2.2
Silicon: . .	0.5	0.4	0.5	0.5	0.6	1.3	0.4	0.2	3.5	2.5
Phosphorus:	. .	. .	0.7	. .	. .	. .	3.1	5.6	. .	. .
Magnesium:	0.2	. .	. .	. .	. .	. .	. .	. .	. .	. .
Manganese:	4.6	. .	. .	5.2	4.5	7.4	2.8	0.9	. .	. .
	9.2	4.	4.8	9.2	10.2	13.1	8.9	8.6	5.8	4.7

The analysis of No. 1, from Lekeberslag in Sweden, is by Berzelius. He considers it to be inferred justly, from the exactitude and precautions of this experiment, that crude iron contains no *oxygen*.

No. 3, from Tredion near Vannes, is very brittle; it can only be employed for ballast.

No. 4, from Lohe in Siegen (duchy of the Rhine) is produced from a sparry carbonate, that also furnishes a natural steel of great reputation. According to an analysis of M. Karsten another sample of this iron contained, 4.9 per ⅛ of combined carbon, and only 0.2 per ⅛ of free carbon.

Nos. 5 and 6, from the furnace of Hamm, which has been already mentioned, are given to show a direct comparison between the white and grey iron of the same works and under the same circumstances. Of *carbon*, it is seen the former contains the most: but M. Berthier's remark,[18] that ordinarily crude-iron containing manganese is white and lamellated, does not seem borne out by these analyses. M. Karsten[19] assures us, that *grey* iron produced from manganesian minerals, contains generally *more* manganese than white iron from the same materials.

The analyses of Nos. 7 and 8, are by Karsten;—the former from Torgelow in Pomerania before mentioned, the latter from the county of La Mark. Both are produced from *bog-ores*, and are cold-short.

No. 9 is from Charleroi in Belgium, and bears the character of the best foundry-iron on the continent of Europe.

No. 10 is from Staffordshire, and called by M. Dufrênoy, *fonte noire*. It is considered as belonging to the class of the best English foundry-iron.

We may remark in both these last, the small quantity of *carbon*, which they contain; and M. Berthier has indicated a similar notice as to their proportion of silicon. I subjoin in a note some other

[18] Voie-Seche: tom. ii. pp. 272, 278.

[19] Metallurgie de Fer: tom. i. § 289.

remarks of the same authority, which may be read in connexion.[30]

The proportions of carbon in the means of the respective classes as detailed in the foregoing table, are for White-iron: . . 3.94 carbon per 100
Grey-iron: . . 2.68 do. per 100,
and appear to warrant the conclusion that white crude iron contains more carbon than grey.

Even if we leave out of the summation for the mean the last two specimens, so as to compare products from *charcoal* only, we shall still have a proportion for Grey iron: . . 2.97 carbon per 100,
which is below that for white iron; and if we omit entirely Nos. 1, 2, 9 and 10, so as to have presented the greatest similarity of constitution, the

[30] 'Coke-iron is not more charged with carbon, than charcoal-iron: but the former is rather characterized by the presence of silicium (or silicon). It seems, however, that as an excess of carbon destroys the properties sought for in steel, so an excess of silicium in coke-iron does away with the tenacity which this substance, when in proper proportion, communicates to the metal. Under certain conditions, this excess of silicium may be removed by submitting the crude iron to a second fusion.'—*Voie-Seche: tom. ii. p.* 274.

This chemist has not stated what should be considered an *excess*: otherwise it is well known that a quality (called by Dufrênoy No. 3 Foundry, but more generally designated as No. 2) which is supposed to contain more silicon than the *fonte noire*, is uniformly taken in cases where strength is required. The No. 1 of M. Dufrênoy, is tenacious in a comparatively low degree; but that arises from other circumstances than the presence of a greater or less amount of silicon.

M. Karsten professes to have found 0.87 per ℔ of silicon, diminishing considerably the tenacity of crude iron. This does not agree with the usual opinion or practice.—*Metall. de Fer: tom. i.* § 250.

means of an equal number of the respective classes will be White-iron: . . 4.07 carbon per 100
Grey-iron: . . 2.97 do. per 100.
We may therefore safely assume that in average constitution, the proportions of carbon in the two classes, are as *four* to *three*, respectively.

Again, it appears that carbon exists in white iron in a different state, from that which distinguishes it in grey iron. With the latter, there is always found more or less *free* carbon, in powder or a state resembling natural *graphite*. In the former, all the carbon is combined with the iron.[21] This appears from the analyses of M. Karsten, an abstract of which I give below. Their object was to ascertain the proportions of the *altered* or combined carbon, and of that graphitic substance, which (so far as its connexion with iron is concerned) may be considered as *unaltered*.

Table shewing the conditions of combination of Carbon *in some specimens of* Crude iron, *in parts per cent. of the Mass.*

	GREY-IRON.					WHITE.	
	1	2	3	4	5	6	7
Combined carbon: . . .	0.89	1.03	0.75	0.58	0.95	4.90	5.30
Free or unaltered carbon:	3.71	3.62	3.15	2.57	2.70	0.20	. . .
	4.60	4.65	3.90	3.15	3.65	5.10	5.30

[21] This is of course to be understood, as applying only to the analysis of a homogeneous specimen of white crude iron. Many specimens, called *white iron*, in practice frequently contain a mixture of grey iron irregularly diffused through the mass; and, if not previously examined with a microscope, lead to erroneous conclusions. Such is the specimen No. 6 on this page.

No. 1 was a specimen of grey iron from the establishment of Sayner near Coblentz. The ore was a brown hæmatite.

No. 2, from Widderstein (Siegen) was a grey iron; produced from a mixture of sparry carbonate and brown hæmatite ores.

No. 3, from Malapane in Upper Silesia; ore not known. All these were made with charcoal.

Nos. 4 and 5 are from Königshütte in Silesia, produced with coke. They are denominated *very grey* iron; and with regard to No. 5, it is noted that the heat of the furnace was not kept up to the same degree, as in the production of No. 4. No. 6 is from Lohe; and No. 7 was a specimen of white iron, in which a large proportion of combined carbon existed, but none unaltered.

This last specimen, M. Karsten considers an example of *carbo-saturation;* inasmuch as exposed, during a long time, under sufficient heat, to contact with lamp-black, its weight was not found to be increased: and he announced it to consist of *two* atoms of iron, united to *one* atom of carbon. With the present system of equivalents, however, 5.3 per cent. of carbon would indicate *four* atoms of iron to *one* of carbon (Fe^4C); and if we were to consider this as the atomic constitution of the percarburet, its proportions would be

Iron: . . .	94.92
Carbon: . .	5.08
	100.

But M. Berthier has shewn that carbon will unite with iron in all ratios, as high as *three* atoms of the former to *one* of the latter (FeC^3); and the composition of such a carburet will be, very nearly,

Iron:	60.
Carbon: . . .	40.
	100.

This compound (FeC^3) is undoubtedly of a physical character quite different from that of crude iron; nevertheless in view of what has been said, and especially our want of knowledge of the influence exercised by the other elementary constituents over the mode of union of these two principals, it does not appear that we are warranted as yet in assigning any definite point of saturation.

The latest examinations into the subject of the different combinations occurring in crude-iron, are those of Dr. Schafhaütl of Munich; who in a paper communicated to the London and Edinburg Philosophical Magazine for December, 1839, advances to the following conclusions.

1°. That *graphite* does not require for its formation such high degrees of temperature, as had been supposed by M. Karsten. The latter metallurgist drew his conclusion, from the circumstance that grey iron (and still more in proportion very grey iron) is only produced, when the temperature of the furnace is highly elevated; although this is not fully borne out by the analysis No. 5, in the table on page 221,

in which there is a notable increase of *free* carbon, though the heat was less. Dr. Schafhaütl believes, he has established the generation of graphite at a temperature not exceeding 1500° Fahr. He does not controvert the general fact of grey iron being usually made when the furnace is working 'hot;' but accounts for it, from the necessity of an extraordinary intensity of heat to effect the reduction of a portion of *aluminium*, which he considers an ingredient of grey iron.

2°. That graphite, as produced in blast-furnaces, is of two kinds; one containing a silicate, the other a carburet of iron.

3°. That with these varieties, the base of both kinds is not entirely carbon, as had been determined by Bouesnel and Karsten, but properly a *carburet of silicon*;—at least in its conditions of existence in the mass of crude iron.

4°. Finally, that these views, resting upon careful chemical analysis, connect themselves with the general notion of the composition of crude iron, and give rise to a new set of elementary distinctions between its two classes; as illustrated in the following paradigm:

GREY-IRON.		WHITE-IRON.	
Iron: . .	Silicet and Aluminet of Iron.	Iron: . .	Carburet of iron, (Cyanuret of iron?)
Silicon: .		Carbon: .	
Aluminium:		Nitrogen:	
Carbon: .	Carburet of Silicon.	Silicon: .	Carburet of Silicon.
Silicon: .		Carbon: .	

The expression of these views, assuming that future analyses will confirm and verify those on which they rest, opens up without doubt a new and fertile field of inquiry and success; but it cannot be expected that all the inferences, contained in and flowing from the principal points which I have exhibited above, should be admitted at once as a sound inductive theory. It is to be regretted too, that from some cause the exposition, from which I have drawn the above conclusions, is not expressed with all that clearness which is necessary for its establishment, or even to do itself justice; but this may disappear or be remedied, hereafter.

Some of the physico-mechanical effects of heat upon crude-iron have been already mentioned; the chemical changes are not less remarkable, though they cannot be so distinctly traced or accounted for. I shall here notice some of the principal of them.

1°. Whenever grey iron, either of the first or second fusion, is cast in moulds or chills (and the same thing may be affirmed to a certain degree in the use of wet sand,) the texture of that part of the mass nearest the chilling surface, is found altered from what it was before; instead of being granular it is now lamellated—it is in short white or *high*[22] iron.

[22] From the similarity in several particulars between steel of cementation and white iron, this term (*high*) which was originally applied to the degree of conversion of the former substance, has been taken to signify in crude iron, a grade of what we have hitherto called *whiteness*.

And this change is produced in greater degree, the more sudden the cooling may be. If the grey iron be suffered to cool down from a state of fusion to a dull red heat, and be then suddenly cooled by immersion in water or otherwise, an analogous effect, though in a converse way, will be observed. The external portion (except a very minute filament or skin) will remain grey iron, having its usual color and crystalline structure; while the internal nucleus will be found converted into white iron. It may be supposed in this case, that the interior was yet in a state of fusion, while the exterior was at a red-heat; and that the crystallizing tendencies, which were allowed to operate on the outside particles, were defeated or disturbed on the inside. It may be stated then, generally, that sudden cooling promotes the conversion of *grey* iron into *white*.

2°. And if white crude iron be exposed to intense heat during a second fusion, and then left to cool gradually and slowly, it is, as is well known, converted into grey iron; so that it may likewise be stated, that slow cooling is necessary for the formation of *grey* iron from *white*.

3°. It is not less so for preserving, during second fusion, that which was before grey. It therefore seems that the difference between the two kinds, so far as the effects of heat are a test, is in crystalline tendencies and action; and that they are, by the application of proper means, reciprocally convertible into one another.

4°. There are some exceptions and peculiarities to be noticed, however, in regard to this last statement; such for instance, as that some kinds of grey iron will not become white, by sudden cooling from the ordinary treatment of a cupola.

This may be accounted for, if we assume that these are various ratios of combination between iron and carbon; and that of these polycarburets, some are more, and others less, fusible or alterable. It also will be admitted, that in many cases the play of elective affinities is better promoted by time and constant influence, rather than by a momentary exhibition of an intense energy. Therefore for such iron, an air furnace would be better than a cupola—there being a longer time, and more uniform heat, and in fact a greater *quantity* of heat, in the former than in the latter; and so, a greater likelihood of the free carbon being fused and thus entering into combination with the iron. I do not know that any analysis has been made of metal presenting this peculiarity, so that we are without means to determine what share other associates besides carbon, may have in producing it.

Another peculiarity in this regard, is that grey iron made with charcoal is more easily made white under sudden cooling, than similar iron produced with coke. This is supposed to arise from the greater fusibility of the product, (in which there is generally more free carbon) as well as from the ingredients themselves—whose crystalline affinities appear to be

different. No *potassium* has hitherto been found in either of the solid products of a furnace: and since the quantity which can be gathered (after a furnace has been blown out) on the tymp, does not account for all that went in among the materials, it has been found necessary to suppose that the remainder has been volatilized and passed off among the gases at the trundle-head. But from a miscroscopic examination of some specimens of charcoal-iron which possessed the peculiarity mentioned, it is by no means certain that a minute portion of this alkali may not unite itself with the iron, and thus communicate to it its different crystalline form.

5°. I will only remark upon one other phenomenon of crude iron subjected to high temperatures; which is, that while grey iron, heated in contact with air to a point just below fusion, becomes very little more malleable than before, (and indeed under certain circumstances a high temperature seems to diminish its malleability,) white iron becomes very ductile. Again, heated without contact of air, *grey iron* remains crude and grey, according to the temperature it has sustained and its period of cooling; while *white iron* (though containing more carbon) assumes, under the same circumstances, a mechanical arrangement and qualities strongly resembling *steel;* in so much that it can be tempered, enough to take a sharp edge. It is supposed that these changes are not dissonant with the views before taken and hereafter to be expressed, of its constitution.

The magnetic and electro-magnetic properties of iron, which are among at once the most curious and the most useful phenomena of its nature, have not yet been developed in all their extent; and as the experiments hitherto conducted have been principally made upon bar iron and steel, the peculiarities in this respect of the different kinds of crude iron are not known, so as to subserve any useful purpose.

What is known, however, may be summed up in the following particulars:

1°. Grey iron is acted on by the needle, with more violence than white iron: but the magnetism impressed is not so permanent.

2°. In this regard, white iron presents a strong resemblance to tempered steel; which is slower to acquire magnetism than bar iron, yet preserves it undiminished longer.

3°. Grey iron made white by sudden cooling, exhibits analogous phenomena to crude iron originally white: so, steel whose temper has been taken out by slow cooling, approaches in its magnetic characteristics to bar iron.

4°. In bar iron of purity, no change of properties in regard to subsequent magnetic affection, appears to be induced by sudden cooling or otherwise.

5°. The inference may be drawn from these observations, that the mode of combination only, of carbon with the metallic iron, affects the *permanence* of induced magnetism; and generally, in proportion to its

amount, that *free* carbon (like other impurities) injures magnetic *permanence*, though not necessarily magnetic *intensity*: and that this last particular is in inverse proportion to the quantities of carbon.

Such are the empirical conclusions upon this subject. In theory, both the intensity and permanence of magnetic currents appear to depend on the polarity and crystalline form of the molecules of the mass. This is recognized in the difference of magnetic effect between hard tempered and soft steel; as well as between steels tempered to different degrees of hardness: the crystals of all of which present different shapes, induced by different degrees of temperature. There is no doubt, too, that the quantity of combined carbon also would affect this polarity.

Mr. Scoresby has shewn, in a small tract recently published,[25] how by observation of angular deviations (and equally by the torsion-balance of Coulomb) a *scale of temper* may be established for all kinds of steels. I have, so far without success, endeavoured to apply a similar method to the establishment of a scale of combined carbon. Should it fail altogether of its ultimate object, it seems however quite applicable to determine, in the case of crude iron, the *degree of temperature* which existed in the furnace at the time of production—a point of importance, difficult to be ascertained in any other way. I shall take

[25] Magnetical Investigations; Part I. London, 1839.

another occasion to lay before the furnace-masters the method which I pursue for this determination.

Finally, abstraction being made of the impurities, the main differences of the two kinds of crude iron seem, in the present state of our knowledge, to be connected with the amount and mode of combination of the carbon with the metallic iron; and with the changes of polarization and crystalline form, to which this combination under various circumstances may give rise. We can trace these changes, from the cubic and granular aggregation of grey iron, up through the minute prisms of white iron of the second fusion, to the fascicular or stellated arrangement in white iron of the first fusion. Mainly, they are to be attributed to the different degrees or variations of temperature, which prevailed in the furnace at the time of fusion or production: but also, in some extent, to the presence of foreign substances, which tend to form with iron and carbon alloys and multiple salts,—each having their own peculiar electric affinities, which they manifest according to circumstances by differences and peculiarities of cohesion and elasticity, capacity for heat, and the superinduction of magnetism: so that whoever wishes to consummate the inductive theory of Iron-Metallurgy, will have to begin by a thorough study of the influence of the so called imponderable agents, upon these several alloys and salts.

SEC. 4. *Gaseous Materials and Products; accompanying the formation of Crude Iron.*

IT was stated on page 168, that in practice, with the coke furnaces in Wales, about *nineteen* tons of atmospheric air were required for the production of *one* ton of crude iron. I propose to inquire briefly in this section, how far this approximate practical statement rests upon a principle of general application to the case of any combustible (raw coal, coke, charcoal, or torrefied wood) that may be employed for the same purpose, and also to indicate such peculiarities as are found to attend a modification of this supply, as regards either Quantity, Density, or Temperature. The considerations pertaining to the mechanical adaptations by which the supply is regulated or kept up, are too extensive to admit of a discussion here; therefore this part of the subject, although of great interest to the metallurgist, will not be mentioned, except when some important phenomena appear to be connected with a peculiarity of mechanical arrangement.

I. The object of the supply of air at all, being entirely to produce a particular mediate effect, the quantity of effect desired to be produced, will, of course, become a measure of the quantity of air supplied. And this measure is ascertainable, by tracing carefully the *immediate* effects that attend the supply. The first of these, is the maintenance of com-

bustion; which could not be kept up, otherwise than by the consumption of the oxygen, one of the atmospheric elements: and another, the property which this element has of combining with the carbon in the coal during combustion, and after contributing to alter materially its physical state, carrying it off through the chimney of the furnace in the shape of a light gas. It is therefore, in fact, by the admission and subsequent decomposition of air, that three-fourths of the vast quantity of solid coal which is continually being put in the furnace, is got rid of in the easiest and most silent manner. An important modification of this last indicated property, is that the combination of the oxygen with the carbon takes place always in certain definite proportions; and we are, from this circumstance, furnished at once with the means of determining arithmetically the quantity of air to be furnished to a furnace, whose charges of combustible are known.

Two proportions of combination between oxygen and carbon are at present recognized; one, forming *carbonic acid*, and the other, *oxide of carbon*. But as the first always takes place accompanied by the developement of more heat, and, without requiring more of the combustible, only demands more oxygen, it is the one which for economy's sake should be always aimed at, and the supply of air therefore regulated accordingly.

An easy rule can be given to find this supply: *Take one-fifth of the weight in pounds of all the charges of the combustible (either charcoal or coke) during one turn of twelve hours; the quotient is the number of cubic feet of air, under the pressure of the atmosphere, to be furnished in one minute.*

Thus, in the case mentioned on page 124, the number of charges per turn was, on an average, thirty-five, weighing 500 pounds each: combining these numbers according to the rule, we then have $35 \times 500 \times \frac{1}{5} = 3500$ cubic feet per minute; the same as derived from the rate of the engine.

By the same rule, the allowance for a charcoal furnace making 4 tons in the twenty-four hours, with the proportion of charcoal stated on page 180, would be 946 cubic feet per minute.

This allowance is stated, as the quantity to be *furnished*. The quantity actually required to convert all the carbon into carbonic acid,[24] will be to the quantity furnished, as the weight of pure carbon in the combustible, is to the gross weight of said

[24] If we call P, the weight in pounds of pure carbon in the combustible; O, the chemical equivalent of the atom of oxygen (hydrogen being 1); O_1 the proportion per cent. of oxygen in the atmosphere; C, the equivalent of carbon; w, the weight of a cubic foot of air at the mean temperature and density; and 720 the number of minutes in 12 hours; we shall have

$$\frac{OP}{3.6\ CO_1\ w} = \frac{0.275\ OP}{CO_1\ w} = Q,$$ the quantity of air necessary, through an entire turn, to convert all the carbon into carbonic acid gas.

combustible. For coke furnaces, the nett weight of carbon is about 75 per cent. of the coke charged; for charcoal, made indifferently from all kinds of wood, the same proportion is 90 per cent.

Taking these average numbers, the consumption of air is given precisely, if we *multiply the gross weight in pounds of the* coke *charged in twelve hours, by the number* 0.157; *or if* charcoal, *by the number* 0.188—*for the number of cubic feet per minute.*

In the case of the coke furnace just mentioned, the consumption is found in this manner, to have been 2747 cubic feet, out of 3500 supplied; and for the charcoal furnace, 889 instead of 946 cubic feet.

This excess is necessary, in order to provide for the discount which is to be made from the calculated duty of the blowing machine, on account of waste at the tuyères, leakage, loss of force from great length of pipe, from elbows, and from irregularities in the bore, etc. etc. The best executed cast-iron bellows will not actually furnish more than *three-fourths* of their theoretical supply; while in many, it will not be more than one-half. The excess would, in fact, have to be greater, were not a considerable quantity of oxygen furnished by the solid materials; which, separating, helps to support the combustion. Although therefore the preceding rules are applicable generally without notable error, in order to be exact, it is desirable in every case to ascertain the constitution (or at least the amount of oxygen) of all the

materials; without knowing which, a calculation might in some cases lead to erroneous conclusions

We will now see how far the considerations here presented apply to an actual case; which has already furnished quantities for some of the preceding tables.

It was supposed in the calculations for a furnace about to be built, that it would carry forty charges of 500 pounds to a turn; and the approximative quantity of air thence deduced (according to a rule similar to the first preceding,) was required to be 4000 cubic feet per minute. The blowing cylinder (of cast-iron) had, with a diameter of 5 feet, a horizontal double-acting stroke of 8 feet; and running at the rate of 13 revolutions (or 208 feet) per minute, furnished theoretically 4084 cubic feet in the same time. From observation, and comparison of its structure, and the arrangement of long and frequently bent pipes leading the air into the furnace, the productive effect of the machine was rated, as nearly as possible, at $\frac{2}{3}$ of its above calculated result; and so, to supply 2723 cubic feet per minute.

The ratio of the weight of all the air supplied in one turn, at this rate of 2723 cubic feet per minute, to the weight of all the coal supplied during the same period, (allowance being made for the actual density of the air as supplied,) is expressed in the table (page 189) by the numbers 260 : 2000; and becomes, in this mode of expression, suitable for the calculation of the absolute chemical affinities, to which we have now progressed.

These 2000 parts of air contain, as shewn in the table, 460 parts of oxygen; while the total quantity of carbon, as derived from all sources, is 239.1 parts. To form carbonic acid, there is required to be present $2\frac{2}{3}$ parts of oxygen for every 1 of carbon; and it is therefore manifest, that except for the addition of oxygen from other quarters, there would not be enough to saturate all the carbon in the furnace. But this addition is always afforded. In the present case the total quantity of oxygen was 665.9 parts; of which, as shewn in the table of recomposition, (p. 191,) 59.8 parts went to the constitution of the cinder, leaving 606.1 parts to form carbonic acid with (239.1—2. 3) 236.8 parts of carbon. Even this, however, was not quite sufficient; and therefore, (as was also visible in the appearance of the flame at the trundle-head, consequent upon every fresh charge of combustible) a certain quantity of carbonic oxide was formed, of course to the disadvantage of the working. By applying well known methods of calculation, it was ascertained that for every 36.30 parts of carbonic acid by weight, there was also produced 3.17 parts of the oxide of carbon; or, what amounts to the same thing, of the whole quantity of carbon-gas produced, 92 per cent. was carbonic acid, and 8 per cent. oxide of carbon. [25]

[25] Without an analysis, it could not, of course, be asserted that these were the constituent proportions of the gas. All that the calculation shews, is that the elements were in sufficient quantities to produce the compounds indicated: and that the existence of such quantities is in some degree connected

I hope I have now succeeded, in making plain the principles, upon which the *quantity* of air supplied, affects the working of furnaces. The modifications arising from there being always formed, during combustion, some other products besides the two principal ones just mentioned, do not appear of sufficient extent to require being treated of here.

II. In speaking of the proportionate weights of the combustible and the air, supplied in a given period, it was remarked that an allowance was made by the calculation for the actual density of the air; and this brings us to a consideration of that particular, which is also intimately allied with the preceding. Every one knows that in the mechanical arrangements about a furnace, there is always some part of the machine (generally the regulator,) in which the blast becomes, as it were, *packed* and condensed; and the measure of its condensation, is its ability to raise a weighted valve of a known area. This area is generally, with the American furnaces, expressed in square inches; and the elastic force of the air is so many pounds per square inch. In Wales, they frequently apply a more convenient method—the *manometer*, or mercurial guage; by which the elastic force above the pressure of the atmosphere, is shewn in

with the favorable working of the furnace, was shewn by the fact that an additional supply of oxygen, furnished by increasing the number of strokes in the blowing cylinder to fourteen per minute, produced a notable effect. I cannot undertake, in the limits of a note, to reconcile this well-observed fact with the result of some analyses that will be given hereafter.

inches of the tube containing the mercury, and is commonly expressed as a *pillar of blast* of so many inches.

The condensation does not arise from the difference between the supply and the discharge, or the excess of the former above the latter, so much as from the proportionate dimensions of the receiving and discharging pipes. After the regulator has been filled by a certain number of strokes of the bellows, all the air that is thrown in, has to pass out. But what comes in, enters by a pipe (it may be) sixteen inches in diameter, while it is carried into the furnace through a nozzle of three or four inches; so that, as equal volumes have to be led through both pipes at regular intervals, the air has first, to squeeze itself down to suit itself to the reduced aperture, and secondly, to pass out with a quicker succession of particles (or, in other words, to move faster) in order to avoid any extreme alteration of its natural state. The measure of the first of these expedients, is the density,—that of the second, is the velocity of the air; and in the same apparatus, these bear a constant and reciprocal relation to one another, as well as to the quantity supplied.

This will be apparent in the examination of the following table, which I prepared some time since, with great care, for another purpose; and whose practical accuracy is as much as the delicate causes and effects that had to be investigated, will allow.

Table shewing the Velocity and Quantity of discharge of Air *from a Reservoir, subjected to various pressures.*

PRESSURE.		VELOCITY in feet per second.	QUANTITY in cubic feet per minute: through a nozzle 1 inch diameter.	WEIGHT in pounds per minute.
Inches of mercury.	Pounds per sq. inch.			
0.0625	$\frac{1}{32}$ oz.	60.92	18.54	1.43 lb.
0.125	$\frac{1}{16}$ lb.	86.07	26.20	2.02
0.25	$\frac{1}{8}$	121.47	36.97	2.86
0.5	$\frac{1}{4}$	171.08	52.07	4.07
0.75	$\frac{3}{8}$	208.67	63.51	5.
1.	$\frac{1}{2}$	239.98	73.04	5.80
1.25	$\frac{5}{8}$	267.23	81.33	6.51
1.5	$\frac{3}{4}$	291.57	88.74	7.16
1.75	$\frac{7}{8}$	313.69	95.47	7.76
2.	1 lb.	334.04	101.66	8.33
.5	$1\frac{1}{8}$	370.58	112.78	9.38
3.	$1\frac{1}{4}$	402.87	122.61	10.36
.5	$1\frac{3}{8}$	431.89	131.44	11.27
4.	2.	458.30	139.48	12.14
.5	$2\frac{1}{8}$	482.57	146.86	12.97
5.	$2\frac{1}{4}$	505.02	153.70	13.77
.5	$2\frac{3}{8}$	525.92	160.06	14.55
6.	3.	545.48	166.01	15.30
.5	$3\frac{1}{8}$	563.86	171.61	16.03
7.	$3\frac{1}{4}$	581.18	176.88	16.75
.5	$3\frac{3}{8}$	597.55	181.86	17.46
8.	4	613.07	186.58	18.15
.5	$4\frac{1}{8}$	627.83	191.07	18.83
9.	$4\frac{1}{4}$	641.87	195.35	19.50
.5	$4\frac{3}{8}$	655.27	199.43	20.17
10.	5.	668.08	203.32	20.82

The first column of this table contains the pressure, as indicated by the manometer before mentioned; and according to which, the other quantities have been rigidly calculated. The second contains the corresponding indications in pounds and fractions per square inch; assuming 30 inches of the barometer to be equivalent to 15 pounds per square inch, as it is

very nearly. The captions to the other columns explain themselves. It is further to be noted, that the calculations have been made to correspond to a uniform temperature of 57° Fahr., which is about the average in Maryland, and to an atmospheric density of 30 inches of the barometer. If greater exactness is desired, so as to suit the actual stand of the barometer for any particular case, it can readily be deduced by interpolating the columns of quantities after the usual methods. The allowance to be made for a different temperature from 57° Fahr., is not so easy of application, without a longer explanation than would be either fitting or necessary.

Besides the connection in which this table is presented, it may also apply to a practical purpose of some interest,—the determination (more accurately than in any other way, except a special and minute measurement and calculation for every individual case) of the quantity of air supplied to a furnace, deduced from data very easy of observation. For this purpose, the numbers in the fourth column are given, including all the allowances and discounts which, experiment has shewn, have to be made from the strict theoretical result: and to apply them in any case, in which the pressure in the regulator (or in the blast pipes, not far from the furnace,) and the diameter in inches of the nozzle to the tuyère-pipe are known, we have only to *enter the second column for the given pressure in pounds, ranging with which,*

in the fourth, is a quantity, that multiplied by the square of the diameter of the nozzle in inches, gives the actual number of cubic feet blown per minute.

Thus, suppose a case of a charcoal-furnace blown into, under a pressure of 1¼ pounds per square inch, through a nozzle of 2½ inches in diameter; we have from the table, $112.78 \times 2\frac{1}{4} \times 2\frac{1}{2} = 571$ cubic feet per minute. This is the quantity actually passed through the tuyère. Under the same pressure, a nozzle of 2 inches would only deliver 451 cubic feet per minute; and if it were required to know the pressure which would attend the discharge of 571 cubic feet through this reduced aperture, we have $571 \div \overline{2 \times 2} = 143.75$, which number, being between 139.48 and 146.86 in the fourth column of the table, shews that the corresponding pressure will be between 2 and 2¼ pounds (or about 2¼ pounds) per square inch.

Also, from this table may be found the diameter of the nozzle, which will deliver a certain number of cubic feet per minute, under a given pressure. So, if the question be, what diameter of nozzle will keep up a pressure of 1 pound on a discharge of 800 cubic feet per minute, we have only to divide 800 by the number (101.66) standing in the fourth column, opposite the given pressure: the square root of the quotient, which is 2.8 inches, is the diameter.

Other applications of the table will, doubtlessly, suggest themselves; but what have been mentioned, are of chief practical interest.

The primary object in furnishing this table, was to shew distinctly the effects produced by the density of the blast. These effects are of two kinds, *mechanical* and *chemical*.

The first is illustrated in the third column; where it will be seen, in how much higher proportion the velocity increases than the pressure. Thus at 5 pounds per square inch, the total density is about 33 per cent. more than at ½ oz. per square inch; while the velocity of the former case is more than *ten* times of the latter. It will therefore be observed, what an important influence a small increase of density has upon the supply.

A limit is, nevertheless, placed to the exertion of this influence; in the first place, in the increased machine-power required, and again, in the mechanical displacement of the cinder, which, together with the deterioration of the metal, would result from exposure to a blast of too great force.[26] The numbers in the column of pressure, do not exceed, however, actual cases.

The *chemical* effect of increased density, is not less remarkable. By referring again to the table, it will be perceived, that the weights (given in the fifth column) are not the product of a *constant* factor with the number of cubic feet corresponding. In fact,

[26] In order to extend this limit as far as possible, the mechanical arrangement is generally resorted to (in furnaces blown through two tuyères) of setting the axes of the pipes in different vertical planes.

the temperature continuing the same, the weight of a cubic foot increases in a regular ratio with the pressure. Air of the ordinary atmospheric density (30 inches barom. 57° Fahr.) weighs very nearly 0.0768 pound per cubic foot; under the additional pressure of 1 pound, the same volume weighs nearly 0.0819 pound; and with 2 pounds, it is raised to 0.087 pound per cubic foot.

Now the oxygen being mixed in the atmosphere by weight, and in a constant proportion that may be taken at 23 per cent., it follows that any increase in the weight of a given volume of air, increases also the weight and quantity of oxygen combined with it. Thus, recurring to the examples just now given, every 100 cubic feet of ordinary atmospheric air give 1.77 pounds of oxygen nearly: under a pressure of

	Volume in air.	Weight of oxygen.
1 lb.	100 c. feet give	1.88 lb. nearly.
2 lbs.	do.	2. lbs.
3 lbs.	do.	2.12 lbs.

It is thus seen, that by increasing the density we in fact furnish a blast more rich in oxygen, supporting combustion more readily, and generating a more intense degree of heat. For whatever end, then, this greater heat is desirable, it will be answered by increasing the density of the blast.

Connected with this subject, is the discussion of the question alluded to in a former chapter, as to the relative effect and propriety of greater *volume*, or

greater *density*, of the blast for a high furnace; some founders in Wales preferring (especially of late) to enlarge the diameter of the tuyère-nozzles, and lessen, or at least not increase, the pressure. In strict mathematical theory (as exemplified also in the table just given) these two quantities are reciprocal; and if it be only to throw in a certain weight of oxygen per minute, for keeping up the heat in the furnace, that end can be attained as precisely by supplying, for instance, 106¼ cubic feet under a pressure of 1 pound, as 100 cubic feet under a pressure of 2 pounds: but I apprehend that, actually, a different chemical effect is exhibited in the two cases. Other things being equal, the oxygen will leave its mixture in a dense atmosphere more readily; a part of it will exercise its affinities towards other substances with more force, and a greater degree of heat be produced than by a blast more rare.[27] But as the object is not

[27] These principles are well recognized as regards *combustibles*; and it appears to me that they may without impropriety be extended, as I have done here, to a *supporter* of combustion.

One argument, adduced to shew the advantage of using light pressure, was the supposition, that as the condensation of bodies is attended with an expulsion of heat, and vice versâ, the sudden expansion of the air when leaving the pipe, would absorb a quantity of heat otherwise effective. But the experiments of Gay-Lussac prove that this is not actually the case.

I have used throughout these remarks the words *density* and *rarity*, to express the relative tendencies of the atmosphere to give up portions of its ingredients: but in fact, these tendencies are in proportion to the *elasticity* of the air, a property not always reciprocal with the density. This is illustrated in the use of hot-blast; whereby the elasticity and consequent aptitude of chemical affinity are increased, though the density, as is seen in practice, may be often diminished.

always to produce the highest possible temperature, but only that degree which suits the fusibility of the materials, the founder should regulate his workings in this regard entirely by the character of the minerals he is using. If they are easily melted, then a suitable quantity of air should be furnished under small pressure; if on the contrary they are refractory, it is without doubt better to increase the pressure, rather than the volume. The wear of the engine, too, is less in this last case.

On this subject of density, I purposely omit any discussion of the effect of the *nitrogen* of the atmosphere; because up to this time its operation (except as an absorbent of heat disengaged by the combination of the oxygen) is obscure, and any views that I might present would be purely speculative.

III. The effects of increasing the temperature of the blast will be considered only under two heads; first, as they concern the working of the furnace, and secondly, as they affect the metal produced. There are, besides, other considerations of great interest, which are too extensive for our present limits.

1. The working of the furnace seems to be affected by a heated blast, in the production of a higher temperature than attends the combustion of the same materials with cold air, in the consequent saving of fuel and air, and in an increased and sometimes different energy of chemical action.

The present state of science does not give us the

data upon which we can calculate, with accurate certainty, the degree and amount of the two first particulars; but it may, nevertheless, serve to fix our ideas on the subject, to present here some of the results of such a calculation, which can be then compared with existing practical statements.

The union of oxygen with carbon to form carbonic acid gas, is supposed to produce heat enough to raise 29.25 times its weight of water, from the freezing to the boiling point; i. e. 180° Fahr. Thus, 1 lb. oxygen, with 0.375 lb. carbon, heats 29.25 lbs. water through 180°, and forms 1.375 lbs. carbonic acid. The whole quantity of heat produced then, is $\frac{29.25 \times 180°}{1.375} = 3829°.1$, which would be the temperature of the carbonic acid, if its specific heat were the same as that of water. But this relation being in fact about 0.221 : 1, it results that the temperature of the carbonic acid (if formed in an atmosphere of oxygen) will be $\frac{3829°.1}{0.221} = 17326°.2$. The carbonic acid being formed, however, in an atmosphere consisting of 23 parts only of oxygen, while 77 are nitrogen, the heat arising from the oxygen has to be distributed likewise (in proportion to its specific heat) to the nitrogen. Now, allowance being made for the diminished specific gravity of this nitrogen, its specific heat may be taken 1.6 times that of carbonic acid, and its quantity, $\frac{77}{23 \times 1.375} = 2.435$ times; so that from both these relations, it absorbs almost four

times as much as the carbonic acid; or what amounts to the same thing, of the whole number of degrees of heat produced by the combustion, *four-fifths* is absorbed by the nitrogen, and only one-fifth, or 3465°, is sensible in the furnace.

This quantity is the measure, then, of the actual heat in the furnace; at whatever temperature the materials may be thrown in, its degree bears some fractional relation to this number; and the saving of fuel may be represented by this fraction. Thus, if the air be heated to 572° Fahr., nearly *one-seventh* ($\frac{540°}{3465°}$) of the entire heat of the furnace will be at once added, and there will be so much less necessity for the same amount of fuel as before. Also, the same fractional part will be set free from the nitrogen, (the equilibrium of temperature existing without it) and we shall have *four thirty-fifths* of the heat economized in this regard, and to be added to the one-seventh already established; thus making in all nearly *one-fourth* of the total heat, and it may be supposed, of the whole fuel necessary for the furnace. [28]

The economy in the air may be approximated in the following manner:

The specific heat of air being 0.2669, that of

[28] The weight of the *air* being so much more than that of all the other materials together, I have considered in this calculation its effects when heated, only. Otherwise, if our data were more exact, it would be proper to take into account the relative specific heats of the other materials, and the influence which their changes of state have on the general temperature.

water being 1., it takes the same quantity of heat for elevating to the same degree (say 572°F.) 3500 cubic feet or 283.57 pounds of air, as for 75.69 pounds of water. The elevation to 572°F. of this quantity of water, will be effected by the combination of 7.76 pounds of oxygen with the suitable quantity of carbon. Therefore, an increase of 540° in the temperature of 3500 cubic feet of air, corresponds to the effect of 7.76 pounds of oxygen, equivalent to 33.75 pounds, or 416.6 cubic feet, of atmospheric air per minute.

Such are the theoretical considerations founded, it must be admitted, upon not the most satisfactory data, that attach themselves to the economy of air and fuel.

In practice, M. Dufrênoy states that a temperature of 612°F. at the Calder works in Scotland, reduced the quantity of blast necessary, from 3500 to 2627 cubic feet per minute. This is nearly twice as much economy as resulted in the calculation just now made: but in that, was not taken into account the increased velocity of the blast on account of its temperature, and its of course actually increased quantity, though under the same apparent pressure. At some places, as in the Works just mentioned, they have found it advantageous to lessen the external pressure; at others, as at the Butterly works, they have aimed at the same object by enlarging the diameter of the tuyère-nozzle.

The saving in combustible is also above the ratio assigned in our calculation, at least in coke-furnaces. The following statement, collected from various sources, will have some interest in this regard:

Locality.	Proportion of combustible used for one ton of iron.		Temp. Fahr.
Raw Coal.	Cold Air.	Hot Air.	
Clyde: (Scotland)	100.	38.5	612°.
Calder: do.	"	31.8	612°.
Coke.			
Clyde: do.	"	64.	450°.
Monkland: do.	"	64.3	450°.
Birtly: (England)	"	61.4	400°.
Codnor Park: do.	"	55.	400°.
Königshütte: (Silesia)	"	88.	380°.
Butterly: (England)	"	50.	360°.
Wednesbury: do.	"	49.6	360°.
Calder:	"	64.3	300°.
Königshütte: (Silesia)	"	86.	223°.
Do. do.	"	87.	196°.
Gleiwitz: do.	"	74.	120°.
Charcoal.			
Riouperou: (France)	"	78.9	450°.
Malapane: (Silesia)	"	86.	426°.
Do. do.	"	75.	290°.

From this table it seems that the higher the temperature, the greater the economy of combustible. The extraordinary saving in the two first instances, arose from the circumstance of the coal (whose loss of weight had been great in coking) being applicable, at the temperature quoted, in its natural state. The average of all cited shews a saving of 34 per cent.

The *limit of temperature* appears to be more practical than theoretical. In the latter regard, it is possible that there may be a degree at which, when attained, the increased specific heat of the air and of the gases formed would absorb all the caloric that had been artificially impressed upon the blast, and its benefit come in this way to be neutralized. But I apprehend that the intrinsic difficulties in the apparatus, are sufficient to prevent this degree from being ever reached. Up to the point already attained, the advantages appear to be in proportion to the temperature; thus at the Calder works, with 300°, the saving of combustible was 35 per cent.,—when raised to 612°, the saving was rather more than 68 per cent. The anomalies mentioned by M. Le Chatelier[29] as signalized in the Silesian furnaces, and which are shewn in the table just given to be an economy *inversely* as the temperature, resolve themselves, it appears to me, into the local peculiarities of the materials, not affecting the general principles which have been substantiated by numerous results elsewhere. There is no doubt that these local peculiarities affect in an important degree the proportionate result; and that at every establishment, there will be a temperature, not the highest, but suiting the constitution of the minerals, which allows of the maximum productiveness and economy.

There appears to be no exception to the expe-

[29] Ann. de Mines: tom. xvi. p. 105.

rience that furnaces with hot-air are more easily kept in train, and their accidental derangements more readily corrected, than with cold air; and this may be referred to the last circumstance mentioned, an increased chemical action.

The process of this action is not to be explained with precision: but of its existence, both analogy and actual phenomena do not allow us to doubt. Thus, almost every substance in nature has its particular temperature which determines its fusion; the habitudes of many substances as they enter into *solution*, are even more remarkable; and not less so, as regards chemical action of all kinds, that an inconsiderable quantity—a few degrees of heat, give rise to or entirely defeat the result. So it may also be with the fusible matters in the furnace. Besides, there are many symptoms, such as the peculiar brilliancy of the tuyère, the color of the flame of the trundle-head, the deficiency that takes place immediately in the heat of that part of the furnace upon increasing notably the temperature of the blast,—which point to a change in the direction and foci of the chemical forces that are at work. It is upon the manifestation of these and other changes produced by heated air, that the theories of Le Play and Bunsen (which in all probability will lead to results fortunate for metallurgy) in good measure repose.

2. The effect upon the metal, produced by an increased temperature of the air, is a point less

clearly defined than those of which we have been treating. As to the increase in quantity, there is no controversy; but the *quality* of hot-blast iron has been by many persons, suspected. I use this word purposely, because until very lately there had been collected no direct evidence on the matter; and such as is now in our possession cannot be considered as decisive, if even the subject plainly admitted of it. I propose to exhibit here, in as few words as possible, the allowed views in this regard; and also to point out a means of evidence which appears to be worthy of resort, but which has not yet been exemplified in the present application.

The quality of the metal produced under different temperatures, may be affected principally in two ways, chemical and mechanical. I shall consider then, separately, these two classes of affections.[20]

The analytic differences of the first class, M. Berthier states to be in the presence of *less silicon* and *more carbon* (at least in its free state, as graphite) with hot-blast iron than with cold. This latter particular is presumed to make the metal more fit for foundry use; which last quality is recognized, in the admission of practical men, that hot-blast iron is

[20] Of course, it is assumed that the metal is produced under both methods of treatment from the same materials. Otherwise, in the use of forge and finery cinder, the application of the hot-blast presents some remarkable phenomena; which, however, it is not my purpose to consider. The small extent to which this material is applied in Maryland, and the disrepute into which its excessive and improper use has caused it to fall in Great Britain, justify the omission.

more *tender* than metal, otherwise of the same apparent quality, manufactured with cold air.

If silicon maintains in crude iron the properties which it is supposed to impart to bar iron, viz: those of *welding*, the deficiency in this element may correspond with the assumed inferiority of tenacity. But the characteristics of the silicets of iron are not yet clearly defined. It is, however, admitted by M. Dufrênoy[31] that to apply crude iron from hot-blast to the preparation of bars, requires generally a modification of materials. Nevertheless, in Maryland, where a great proportion of the bar iron is from hot-blast, even this admission need not be made.

The synthetic differences of the same class, are seen in a greater liquidity of the hot-blast metal at the moment of reduction and flow, both in the first and second fusions. Also, the changes in cooling from grey iron to white, and vice versâ, are supposed to have place with more facility, than in cold-blast. But hot-blast crude iron is much more rarely white, with the same materials.[32]

The differences of the second class are to be looked for in the proportionate tenacity and resistance of the metal, both crude and in bars, manufactured in the respective methods; and in their rela-

[31] Voyage Metallurg. tom. i. p. 496.

[32] With some materials and the use of hot-blast, I have understood that the whitening can be produced and regulated by inclining the blast-pipe downwards, more or less. This phenomenon is similar in theory to the action of the arrangement before mentioned, of tuyères at different heights.

tive specific gravities. From a few observations, I am led to conclude that cold-blast iron is lighter than hot-blast; but my experiments have not been sufficiently extensive, to assert this universally.

The indirect evidences of the former characteristic I shall not advert to, except to say that the castings, (such as bridge-trusses, etc.), the rolled iron, and the machinery, made from one establishment (the Butterly works) using hot-air, are not less highly esteemed in England than similar products from any other establishment using cold air exclusively. The same remark will apply, with greater extent, to the production of iron in Maryland.

The direct evidences consist in the trials which have been made, with the specific view of determining the cohesion of the two kinds. Of these, the best authenticated are those of Fairbairn and Hodgkinson; from whose extensive tabulated results[33] I have collected the data of the following statements:

I. *Table shewing the absolute and relative Cohesion in several specimens of Hot-Blast and Cold-Blast Iron, respectively.*

LOCALITY.	ABSOLUTE COHESION, or resistance to being pulled asunder, in lbs. per sq. inch.		RELATIVE COHESION, or resistance to being crushed, in lbs. per sq. inch.	
	Hot-blast.	Cold-blast.	Hot-blast.	Cold-blast.
Carron No. 2:	13505 lbs.	16683 lbs.	108540 lbs.	106375 lbs.
Carron No. 3:	17755	14200	133440	115442
Buffery No. 1:	13434	17466	86397	93385
Coed-talon No. 2:	16676	18855	82734	81770
Mean: . . .	15342.5 lbs.	16801 lbs.	102528 lbs.	99243 lbs.
Ratio: . . .	913 :	1000	and 1033 :	1000

[33] British Association Reports: vol. vi. p. 337, etc.

II. *Table shewing the Ratio of respective Cohesion and of Stiffness in several specimens of Hot-Blast and Cold-Blast Iron.*

LOCALITY.	TRANSVERSE STRENGTH.		RESISTANCE TO IMPACT.		STIFFNESS.	
	Hot-blast.	Cold-blast.	Hot-blast.	Cold-blast.	Hot-blast.	Cold-blast.
Carron No. 2:	991.	1000.	1005.	1000.	931.	1000.
Buffery No. 1:	931.	1000.	963.	1000.	893.	1000.
Devon No. 3:	1417.	1000.	2786.	1000.	981.	1000.
Mean ratio:	1113.	1000.	1585.	1000.	935.	1000.

The results in this table, so favorable to the hot-blast, seeming in some degree dependant upon the anomalies (if it is not improper to give them such a name) observed in the several specimens of Devon No. 3, the experiments upon this resistance were continued and extended; so as to neutralize, by a wide average, the indications which are more properly due to the materials themselves than to the method of treatment. I have condensed the report of these numerous and recent trials, into the following table.

The pieces experimented on, were all 54 inches between the supports, and 1 inch square; the actual breaking weight, as well as the calculated cohesion, are shewn; but the flexure before fracture I have omitted, as not essential to our present purpose. Each set of experiments comprehended at least four different trials of the same specimen.

III. *Table shewing the Transverse strength of Hot-Blast and Cold-Blast Iron, respectively.*

COLD-BLAST.			HOT-BLAST.		
	Breaking weight.	Cohesion per sq. inch.		Breaking weight.	Cohesion per sq. inch.
Maximum obs'd:	567 lbs.	45927 lbs.	Maximum obs'd:	537 lbs.	43497 lbs.
Minimum do.	408	33048	Minimum:	378	30618
Mean of 18 sets of experim'ts:	460	37260	Mean of 20 sets of experim'ts:	443	35883

Ratio; (the cohesion of cold-blast being 1000) 1000 : 963.

The conclusion seems warranted from these statements, that for all practical purposes, where the strains are transverse or crushing, the difference is too small to be regarded. When the stress is longitudinal, and the fibres pulled asunder, the ratio is unfavorable to the hot-blast. This may be attributed, I apprehend, to the peculiar crystallizations of the two kinds of metal, and to their different modes of being acted upon. The examination of these peculiarities and differences, constitutes the new species of evidence to which I just now alluded.

Seen under a high magnifying power, the texture in several specimens of hot-blast iron appears to be composed entirely of cubes; while cold-blast is frequently, though not universally, made up of octahedrons and derivative forms. If we suppose the attraction of cohesion in the mass, to be of the same kind with the polar forces that impress the crystalline form, by analogy we may expect a greater developement of that attraction in the latter shape than the former. But the observations on this head have

not been sufficiently extensive to allow of an accurate generalization; and I content myself, therefore, with a mere indication of their principles, in order to induce the co-operation of other examiners. If there be any permanent general difference between the two kinds of metal, there is every probability that it will manifest itself to some extent in the texture; and the reward for the trouble of these microscopic researches, be the establishment of a criterion of greater sureness and precision than we have before possessed, whereby we may judge of the mechanical properties of a material of such varied and important application.

A knowledge of the constitution of the *gaseous products* of the furnace (the last topic that we have to consider) is of great interest, as illustrating the agencies and modes of action among the materials, the different functions of various parts of the stack, and the best methods of applying these products themselves to some practical use. Unfortunately, not much attention has been paid to this subject; nor am I acquainted with any analysis in a case where the quantity, density, and temperature of the air, as well as the weight of the other materials simultaneously acted on, were in the proportions of which modern improvements have shewn them to be advantageously susceptible. To complete, however, the circle of analyses, which I have thought of inte-

rest to furnish in this Report, I present here two, by two different investigators. The first is from a charcoal furnace; the temperature of the blast being 383°F. and the pressure a half pound per square inch. [34]

	By volume.	By weight.
Aqueous vapor: . . .	0.117 . . .	7.37
Carburetted hydrogen: .	0.036 . . .	2.03
Carbonic oxide: . . .	0.156 . . .	15.31
Carbonic acid:	0.125 . . .	19.32
Nitrogen:	0.566 . . .	55.97
	1.	100.

The other is likewise from a charcoal furnace, when the pressure was about $\frac{1}{8}$ pound per square inch, and the temperature 412°F. The means employed in the analysis, were not such as to give the amount of aqueous vapor; but they furnish on the other hand the proportions of free hydrogen, instead of presenting it (as in the former) all under the head of hydro-carburet. In 100 parts by weight, M. Bunsen found: [35]

Hydrogen:	0.25
Carburetted hydrogen: .	1.79
Carbonic oxide: . . .	25.81
Carbonic acid:	16.57
Nitrogen:	55.58
	100.

[34] Ann. des Mines: tom. xvi. p. 569.

[35] Ann. des Mines: tom. xvi. p. 204.

The coincidence of these analyses in the proportions of nitrogen is exact enough; but the differences in the ratios of the oxide and acid of carbon, are very marked. I do not find, in either, any thing to invalidate what was before said, as to the necessity of furnishing oxygen enough to allow of all the carbon combining with it as carbonic acid; though it does not follow, that such combination will be in totality made.

So far as experiments have yet gone, it seems that the combination-modes of these two elements vary much in different parts of the furnace. Thus, in the case just given, the proportion of carbonic acid was 17 per ⅛ nearly at the trundle-head, while at five feet below it was 3.5 per ⅛, but at eight feet below it had mounted up to 7.6 per ⅛. From these observations, M. Bunsen draws conclusions as to the functions of different stages of the furnace, according to the prevalence of one or other element about each stage. The first, which he supposes to extend four or five feet below the trundle-head, is the *preparatory* stage; the materials are there dried,—great quantities of aqueous vapor and carbonic acid are there formed,—and things are put in a train for the second or *reducing* stage. This is characterized by the great proportion of oxide of carbon (from 25 to 33 per ⅛), and extends to the lower part of the boshes; the iron begins to be reduced to the state of a magnetic oxide, but the heat is not intense enough to separate

it from the earthy silicates by bringing them to a state of fusion. The third is the *separating* stage; where the fused materials arrange themselves in the order of their weight, the iron below, the cinder above, and admit readily of removal to their respective destinations.

This theory, somewhat similar to that of M. Le Play, is, in part, a substantiation of the opinion of practical men, as to the office of the upper portion of the furnace; insomuch that it was once proposed (though I do not know if it was ever attempted to be executed) to erect a furnace of such a height in proportion to its diameter, as to allow all the materials to be supplied in their natural state;—the *roasting* in short, and *coking*, were to be done in the furnace itself.

As to the functions of the other stages, we have not yet sufficient data for their determination.

I pass now from these speculative considerations, to the economical uses which the gases from the furnace, and the great amount of heat otherwise lost in them, may be made to subserve.

1°. They may be employed to heat the air which is blown into the furnace. This is an application very common throughout Maryland, and is found to answer a good purpose. Only it may be remarked, that there is, in every instance which I have seen, still a great loss of heat from the arrangements which

are used to convey the blast downwards to the tuyères. It may, I think, be easily demonstrated, that the advantage gained by increased temperature would more than compensate for the interests upon improved air-conduits.

These improvements would, however, only be applicable to charcoal furnaces. It would be hardly possible, except by disproportionately expensive precautions, to retain the high temperature which is found most advantageous for coke furnaces; and accordingly, all trials of this kind which have been made for the latter, have proved unsuccessful, or at least have not realized their expected and habitual value.

2°. Another application is to the carbonisation of the wood or coal, and to the roasting of the ores. The former of these uses is already becoming very general in Germany, and is being introduced into France. In Great Britain, avail has not yet been taken of it, because of the fortunate association of their iron-ores with the coals, and the great abundance of the latter; so that the cost of coking, as has already been shewn (p. 164) is not more than one-half of the cost in France. The roasting of the ore, too, is mainly done with coal that would be otherwise wasted.

The arrangements for this object are not difficult to conceive or execute, and have already been made the object of special descriptions by several writers.

I shall, therefore, not pause to discuss them farther here.

3°. Similar descriptions have been likewise given of another way of using the gases; namely, for raising and sustaining the steam of the blast-engine. At Niederbronn on the Rhine, such an apparatus from a small furnace, (the boilers being placed on the stack) conducts the steam to the cylinder by a copper pipe 4 inches in diameter and 50 feet long, with a loss of tension of only 4 pounds;—the pressure in the boilers being 40 pounds per square inch. Sufficient heat, however, can be applied, to raise the pressure to 60 pounds per square inch. It is calculated that the engine, worked in this manner, (the diameter of the trundle-head is only 3 feet) exercises a force of 25 horses.

So little heat is required for this object (according to M. Bunsen, only *one-twelfth* of that contained in and lost with the gas), that the supply and heating of the air, could be accomplished at the same time and with the same apparatus.

4°. The last application that I shall mention, is to the re-melting of iron itself, in a reverberatory or other furnace. This, which at first to some philosophers seemed doubtful (although it has been already shewn in these pages that not more than *one-fifth* of the total heat was available for the fusion of the materials) has, like the preceding, been practically proved. So, at the furnace of Niederbronn, just mentioned,

they melted in a reverberatory furnace, heated only by the gas brought down from the high furnace and carried a distance of more than 70 feet from the stack, 668 pounds of crude iron in one and a half hours. The fusion was perfect; and it moulded easily and well. I mention this case, in order that practical men may have a better idea of the amount of heat furnished by this agent.

In regard to the quality of the iron cast in this manner, no examination seems to have been yet made.

APPENDIX.

Table shewing the Quantity of Pig and Bar-Iron imported from Maryland into Great Britain (Scotland not included) for the years undermentioned, from 1710 *to* 1755; *referred to in page* 59 *of the Report.*

DATE.	PIG-IRON.				BAR-IRON.				REMARKS.
	T.	*C.*	*Q.*	*lbs.*	*T.*	*C.*	*Q.*	*lbs.*	
Up to Christmas, 1718	:	:	:	:	3	7	0	0	The returns are from 1710, but no imports were made till 1718.
1729	852	16	1	11	:	:	:	:	
1730	1526	15	1	15	:	:	:	:	
1731	2081	2	0	27	:	:	:	:	Duty on Bar-iron per ton, £2 1s. 6.15d. sterling.
1732	2226	3	2	0	:	:	:	:	
1733	2309	11	3	22	:	:	:	:	
1734	2042	2	2	3	:	:	:	:	Duty on Pig-iron per ton: 3s. 9.45d. sterling.
1735	2862	8	0	17	44	9	0	21	
1739	2242	2	2	14	:	:	:	:	
1740	2020	2	0	22	5	0	0	0	No printed returns appear to have been made from 1719 to 1728 inclusive: nor for 1736 to 1738 inclusive.
1741	3261	3	1	5	5	0	0	0	
1742	1926	3	1	5	:	:	:	:	
1743	2816	1	1	15	:	:	:	:	
1744	1748	4	1	3	57	0	0	0	
1745	2130	16	1	10	4	5	2	14	
1746	1729	1	0	2	193	3	3	12	
1747	2119	0	3	24	82	11	2	11	
1748	2017	11	3	10	:	:	:	:	
1749	:	:	:	:	:	:	:	:	No return.
1750	2508	16	1	25	5	17	3	0	
1751	2950	5	3	15	3	4	2	9	
1752	2762	3	0	4	16	10	2	21	
1753	2347	9	2	18	97	18	0	19	
1754	2591	4	3	17	153	15	1	3	
1755	2132	15	1	22	299	1	3	0	

This table, as well as the following one, has been compiled from a more diffuse series, which forms part of an appendix to an interesting Memoir on the Iron trade by Mr. Scrivenor, now in process of publication in the London Mining Journal. From the way in which the tables are there printed, it is not easy to separate Virginia from Maryland: therefore, in many cases (especially in pig-iron) the amount represents the joint export.

The returns appear to have been at first made when called for by Parliament to enlighten some exigency of legislation. Hence the occasional intervals which are signalized in the remarks. At least my authorities give me no other explanation.

Table shewing the Quantity of Pig and Bar-Iron imported from Maryland into that part of Great Britain called Scotland, for the years undermentioned, from Michaelmas, 1739, *to S. John Baptist,* 1756; *to accompany the preceding table.*

DATE.	PIG-IRON.				BAR-IRON.				REMARKS.
	T.	*C.*	*Q.*	*lbs.*	*T.*	*C.*	*Q.*	*lbs.*	
Michaelmas, 1742–3	1	12	2	18	1	16	3	18	The returns are in fact from 1739, but no imports were made until the date mentioned.
1744–5	27	14	3	0	:	:	:	:	
1748–9	144	16	0	18	:	:	:	:	
S. John Bapt. 1750–1	:	:	:	:	:	:	:	:	No imports for 1742–4; nor for 1746–8.
1752	35	0	0	0	:	:	:	:	
1753	20	0	0	0	:	:	:	:	Of the entire import from the colonies during these 10 years (1739–49) Maryland furnished nearly *three-fourths*.
1754	25	0	0	0	:	:	:	:	
1755	:	:	:	:	:	:	:	:	No returns from 29 Sep. 1749, to 24 June, 1750.
1756	:	:	:	:	:	:	:	:	Of the entire quantity imported in these 6 years Maryland furnished rather more than *one-third*.

In the Documents from which this Table has been compiled, the different colonies are kept carefully distinct.

Table shewing the dates and other particulars of the several writs of ad quod damnum, *granted out of the Provincial Chancery of Maryland, in pursuance of the act of* 1719, *ch.* 15, *'for the encouragement of an Iron Manufacture,' etc. between the years* 1733 *and* 1767.

DATE OF PRECEPT.	DATE OF PATENT.	NAMES OF GRANTEES.	LOCALITY.	COUNTY.	REMARKS.
1733, Jan. 12	1734, Sep. 5	† B. Tasker, C. Carrol, D. Dulany, Dr. C. Carrol, D. Carrol of Duddington,	100 Acres on Charles branch and Gwin's falls,	Baltimore	The furnace had been erected prior to 4 March, 1733.
1734, Feb. 5	. . . .	† John Ruston,	100 A. on North-east river; part of N. E. Manor,	Cecil	1736, Aug. 31, assigned to Wm. Chetwynd of Beddington, Surrey, Eng. no patent found.
1735, Mar. 8	1745, Jan. 23	B. Tasker, C. Carrol, D. Dulany and Dr. C. Carrol,	100 A. on Maiden's Choice and Gwin's falls; part of *Georgia*,	Baltimore	Damages assessed at from 3*s.* to 18*s.* currency per acre.
1744, Apr. 12	. . . .	Dr. C. Carrol of Annapolis,	100 A. on N. E. run of Bush river,	Baltimore	Now Harford; damages £75 currency.
1746, Feb. 27	1750, . . .	Isaac Webster, John Hall and Jac. Giles,	70 A. on Bush river, near the Quaker M. H.	Baltimore	Now Harford; near Bynam's run, patent undated.
1746, Mar. 6	1750, Oct. 27	† Sir Nicholas Carew, Bart. Osgood Gee and others,	100 A. at the head of Back river and on Herring run; part of *Kingsbury resurveyed*,	Baltimore	Now Harford; damages £92 10*s.* currency; ground-rent £4 sterling per annum.
1747, Feb. 11	1748, Apr. 30	Daniel Dulany & Co.	100 A. on Gwin's falls; part of *Georgia*,	Baltimore	Damages £90 currency; opposite Baltimore Co's furnace.
1748, Sep. 2	1749, Jan. 22	Ed. Neale, Wm. Bennett and Ralph Falconer,	100 A. on Deer creek, opposite Thomas' run; part of Diamond's Rich point,	Baltimore	Now Harford.
1748, Sep. 23	1749, Mar. 2	George Rock of Baltimore county, ironmaster, and Samuel Fisher, slitter,	100 A. on Deer creek; part of a tract called Sim's Tents,	Baltimore	Now Harford; damages £50 currency.
1749, May 18	1749, Aug. 29	Col. John Hall & Co.	100 A. on Deer creek; part of Rigbie's Hope,	Baltimore	Now Harford; damages £[illegible] curr., ground-rent £[illegible] sterling.

1753, Oct. 11	. . . .	† C. Carrol, Dr. C. Carrol, B. Tasker Jr., C. Carrol Jr., D. Dulany Jr., and Walter Dulany,	100 A. on Jones' falls; part of Mount Royal,	Baltimore	There appears only an inquisition, but no patent.
1755, July 29	1755, Nov. 3	† Caleb Dorsey, Alexander Lawson and Edward Dorsey of Annapolis,	100 A. on Elkridge, and on a run of Patapsco near C. Dorsey's house,	Baltimore	Damages £300 currency.
1758, Mar. 3	1758, Dec. 12	Dr. James Walker,	100 A. on a run called Stoney run,	A. Arund.	
1758, Aug. 8	1759, Apr. 12	† Caleb Dorsey, Alexander Lawson and Edward Dorsey,	100 A. on Long Bridge B. head of Curtis creek,	A. Arund.	
1759, Nov. 28	1762, Feb. 11	† Charles Ridgely,	100 A. on the south side of the main falls of Gunpowder, and on Patterson's great run,	Baltimore.	
1760, June 14	1760, June 21	C. Carrol, B. Tasker Jr., Daniel and Walter Dulany, C. Carrol Jr. of Duddington, and Barrister C. Carrol,	100 A. on the main falls of Patapsco, at the fording place between Baltimore and A. A. counties, or near navigable water, above said ford,	Baltimore	Now Elkridge landing.
1761, Mar. 5	1762, Dec. 11	Benjamin Jacobs,	100 A. on Unicorn creek,	Q. Anne.	
1761, Oct. 6	1762, Aug. 27	Rob. Adair and Archibald Buchanan,	100 A. on a draught of Deer creek, near the mine Old-fields,	Baltimore	Now Harford..
1762, Mar. 25	1765, Jan. 25	† David Thomas, Jesse Hollingsworth, John Roberts, David Davis and Thomas May,	100 A. near Sweet run, adjoining the main fresh run of Elk river, in N. Milford hundred,	Cecil.	
1762, Sep. 30	1765, July 13	† James Russell, Walter and John Ewer, John Buchanan and Alexander Lawson,	100 A. near the mouth of the Great falls of Gunpowder; part of James' Park and Onion's Second Thought,	Baltimore	Now Harford.
1765, Sep. 27	1770, Oct. 29	Littleton Dennis of Worcester county, and Josiah Polk of Somerset county,	100 A. on main branch of Wicomico river, above the bridge; part of Cockland and Pemberton's Good Will,	Somerset	Damages £37 10s. currency.
1765, Nov. 1	1768, Nov. 11	† Launcelot Jacques and Thomas Johnson Jr. of Annapolis,	100 A. on Green Spring run, about two miles from Fort Frederick,	Frederick	Now Washington Co.
1767, Sep. 18	1768, Apr. 11	† Launcelot Jacques and Thomas Johnson Jr. of Annapolis,	100 A. on Licking creek,	Frederick	Now Washington Co.

After this last date no more writs for the purpose appear to have been obtained: and the act authorizing them, although not repealed, seems to have fallen into disuse. A similar act for the encouragement of water mills in the province; (under which, more than a hundred writs of *ad quod damnum*, are among the Chancery Records,) was regularly repealed in 1776; with which was probably associated in general opinion the one under consideration.

There were also two other acts for the Encouragement of Adventurers in Iron-works; viz, 1732, ch. 17, and 1336, ch. 17. Both of these are affirmed in the Capitularies to have been repealed by the act of November, 1779, ch. 14; though in this I think there is some mistake.

I have marked † those which I have reason to believe went into operation: for the others, I should with pleasure receive information from persons who have nearer means of knowledge.

PLATES.

PLATE I.

Fig. 1, and 2, are a section and ground-plan of an ancient furnace, described by Agricola as in use in his time; in which they treated very fusible ores.

h, is the hearth in both figures.

b, the bellows, and

t, the tuyère.

These figures are from Hassenfratz.

Fig. 3, and 4, are, in like manner, a section and ground-plan of a furnace described by Agricola; calculated for ores more refractory.

h, is the hearth or crucible, in both figures.

t, the tuyère in fig. 4.

b, the place of the bellows, which were similar to those already given.

n, the nozzle of the bellows.

Both of these kinds were *stück-ofen*, or *fourneaux-a-masse*.

Fig. 5, and 6, shew an improvement, likewise in the time of Agricola; which was certainly the germ of the *fluss-ofen*.

h, is the crucible in both figures.

t, the tuyère.

b, the place of the bellows, whose nozzle is shewn, and which were of a larger and more powerful kind.

l l, shew the steps for the convenience of charging.

s, in fig. 6, shews the battered faces of the furnace.

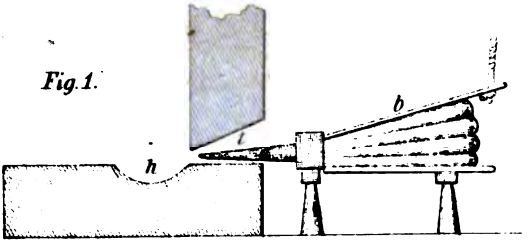
T, the aperture answering to the modern tymp-arch.

f, an opening whereby the slag, and perhaps the iron, were discharged.

The scales appended are arbitrary.

PLATE I

Fig. 1.



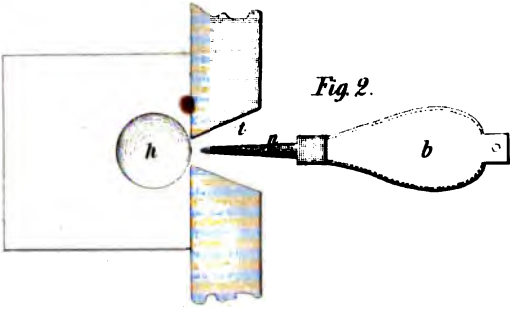


Fig. 2.

Fig. 3.

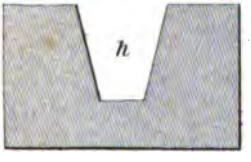
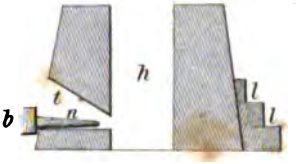


Fig. 5.



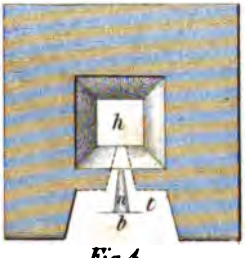


Fig. 4.

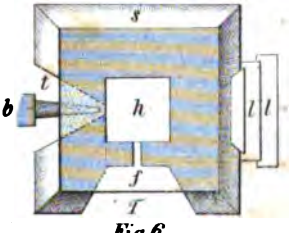


Fig. 6.

Scale of Feet for Fig. 1. 4.

Scale of Feet for Fig. 5. 6.

Lithographed by E. & J. Weber & Co. Baltimore.

UNIV. OF M.

PLATE II.

Fig. 1, is a drawing in peculiar perspective, (which may be denominated *isomeric*,) to shew some remarkable points in the furnace mentioned in p. 117. of the Report. It is supposed that the drawing can be explained without letters.

The inclination of the beds of the stones and the joints, on two sides of the furnace, are distinctly seen. Also, the rail-way for charging, is seen crossing the trundle-head. The cars used for this purpose, are shewn in Plate III.

Fig. 2, is the simplest form of manometer, or mercurial guage, for ascertaining the pressure of the air in the regulator or blast pipes.

a b d, is a glass tube, bent as shewn, and containing mercury to any level *m m*.

c k, is a cork, through which the tube passes, and which fits tightly the aperture that may be made for introducing the end *a* of the tube.

s e, is the scale, which may be marked in inches and parts, or in ½ pounds, at pleasure. The scale slides up and down the tube so as to allow the index, at *e*, to coincide with the actual level in the descending arm of the tube.

The difference of level in the two arms is due to the pressure, at the rate of ½ pound per inch, in height of the mercury in the ascending tube.

Fig. 3, and 4, shew an apparatus, for ascertaining the temperature of the blast.

p e, shews in fig. 3, a section of the upper part of the circumference of a blast pipe; and in fig. 4, a ground-view of the same pipe.

f f, in both figures, is a circular flange, with a collar or throat *g g*, in which a screw-thread has been tapped for receiving a corresponding neck, *n n*, through which passes, attached and air-tight, the bent thermometer, *t t t*, whose bulb, when in position, is thus inside of the blast pipe.

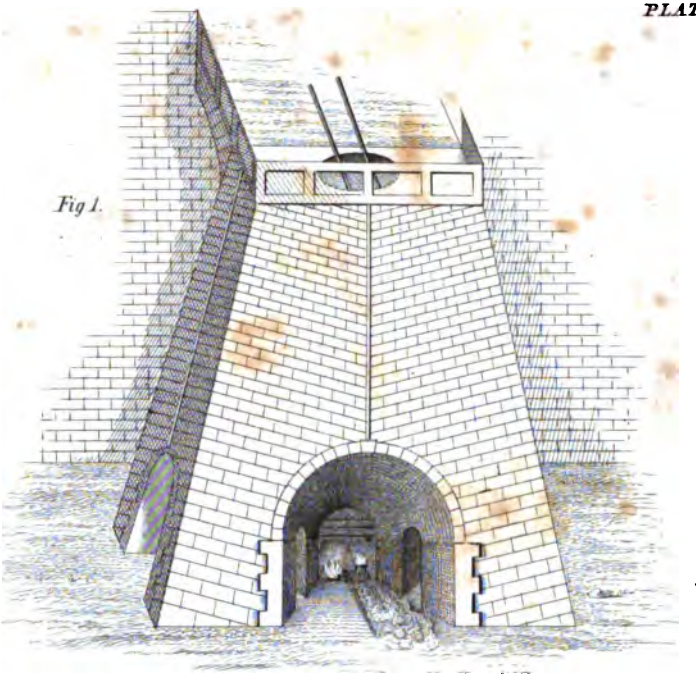
At the end *v* of the scale, the thermometer may be supported with a piece of charcoal, or other non-conducting substance.

The thermometer is graduated to 550° or 600°, for every 5° of Fahrenheit. Although the expansion of mercury at these high temperatures is not so equable as below 212°, it is yet the most unexceptionable indicating medium that can be employed. For the temperatures that will probably be found to suit best the materials and apparatus employed in the charcoal furnaces of Maryland, (from 200° to 300°,) it is sufficiently uniform.

A more simple, and sometimes more convenient arrangement might be found in dispensing entirely with the flange and collars, and allowing the thermometer, with its neck, *n n*, (whose screw need not be more than ¼ inch) to screw at once into the pipe, which would be tapped to suit its reception.

PLATE II

Fig 1.



Original Scale

Isometric Scale

Fig 2.

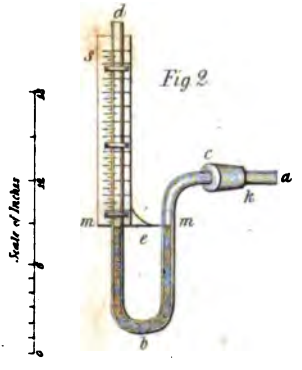


Fig 3

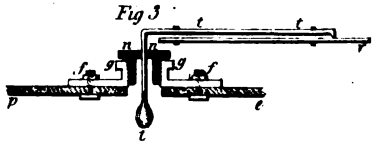


Fig. 4.

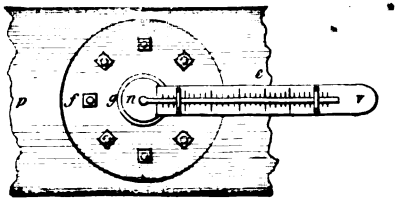


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PLATE III.

Fig. 1, and 2, are a side and end elevation of the cars, used for charging at the furnace shewn in Plate II.

a b c d, is the car-body of plate-iron fastened by iron straps to the truck, and having a conical bottom *b e c*; to the apex of this cone is fastened the vertical stem *e f*, which is racked (fig. 2) at its upper extremity, and is susceptible of a motion upwards and downwards by means of the pinion *g*. The motion of the stem is guided by two bars, *h h*, whose ends are shewn in fig. 1, and the side of one in fig. 2. The pinion is fitted to a long axle, *i k*, and is worked by the winch, *k l*. The other parts do not need a particular description.

In the car from which this drawing was made, every part was of iron. As the kind used, *angle-iron*, is not common in America, I have altered some of the dimensions of the pieces of the bed, to suit a structure of wood.

As soon as the winch turns, the stem *f e* descends, and the materials begin to slide off all around the conical bottom. The discharge is very rapid, and evenly distributed; and great benefit has been found to result from this method above the old one, where unavoidably a large part of every charge is heaped on one side of the stack.

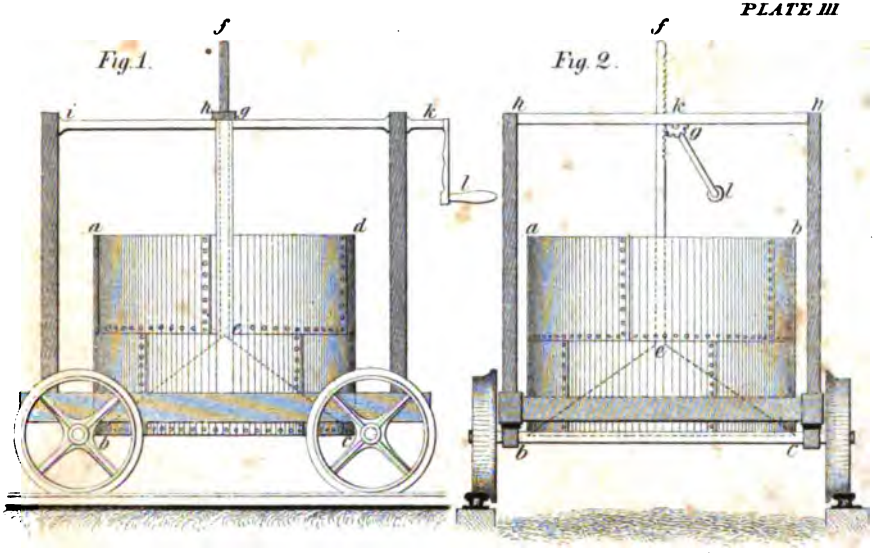
Fig. 3, and 4, are cars used at the same furnace, but principally for limestone.

a b c, in a side view, and *c b b b c*, an end elevation of the car body; which is in two parts, opening in the middle as shewn by the line *b d* on fig. 3,—*e f* and *g h*, are two flat bars fastened at one end, respectively, and at the other sliding through the staples *i i i i*. The end *h*, of the upper bars is prolonged on both sides of the car as seen in fig. 3, and has a catch at *k*, in which fits a corresponding projection in the arm *m n*. This projection can be released at any time by throwing up the arm, whose motion is on the pivot *n*.

By this means the discharge is effected. When the car is over the trundle-head, the filler who pushes it by the bar *m m*, fig. 4, lifts that up; the catch at *k* is released; there is no longer any obstacle to the weight of the materials forcing asunder the body, which slides on the longitudinal joists of the bed, opening at *b b b*, and arrested, when it has sufficiently opened, by the cleets *p p*, respectively.

The rails shewn on this plate are hollow, as mentioned in the text, and are kept from burning out by a stream of water which is passing through them, and is then conducted, all heated, to the steam engine.

PLATE III



Scale of Feet

1 2 3 4

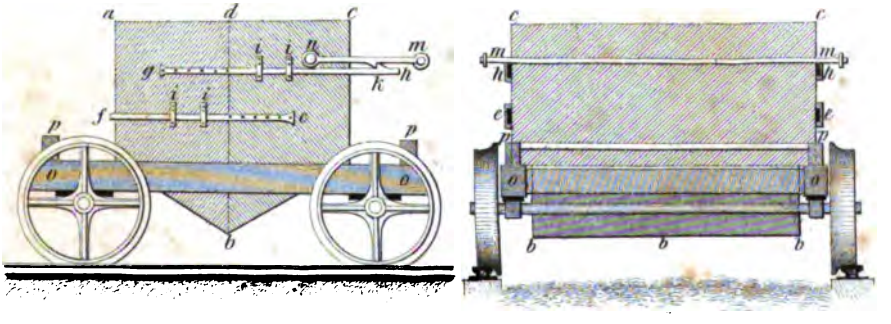


Fig. 3.

Fig. 4.

Lithog. by E. Weber & Co. Baltimore

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P. P. Tyson

with the regards of

J. H. Alexander

5 Dib. c Mark. III.

SECOND REPORT

ON THE

MANUFACTURE OF IRON;

ADDRESSED TO THE

GOVERNOR OF MARYLAND:

BY

J. H. ALEXANDER,

Late Topographical Engineer of the State.

PRINTED BY ORDER OF THE SENATE.

ANNAPOLIS:

WM. McNEIR, PRINTER TO THE SENATE.

1844.

TO HIS EXCELLENCY

FRANCIS THOMAS,

GOVERNOR OF MARYLAND.

I HAVE the honor to present to your Excellency, herewith, a Second Report on the Manufacture of Iron; whose details, I believe, will be found of valuable application among the furnaces of Maryland.

I have not included any statistical details (the collection of which so far has cost me much labor, and more) for the reasons which I have given in the General Preface. And I still entertain the hope expressed in the former Report, that the acquisition of such information, in regard not to Iron only, but to other subjects, will be thought of sufficient importance to warrant its being given in charge to some of the existing State-officers.

That a considerable part of this Report is not my own original material, will not, I conceive, be any objection to it: many things are said in it, better than I could have said them myself; and in the relation that I hold to it, I may venture upon the anticipation for it (which I could not allude to, otherwise) of your Excellency's favorable consideration.

I beg your Excellency to accept the assurances of my profound respect.

J. H. ALEXANDER.

BALTIMORE, 14 *February*, 1844.

GENERAL PREFACE.

In giving as a Second Report on the Manufacture of Iron to the Governor of Maryland, Rogers' Letters on the same subject, I am carrying out an early design, which would have been executed at the time of furnishing the former part for publication, had I not apprehended that it would produce a document, on several accounts disproportionately voluminous. As, however, I have been informed in sundry ways that the former Report is in a measure answering its purpose, by being well received among those for whose service it was chiefly intended, I very cheerfully apply myself to the fulfilment of my original plan, by presenting here complete, a work which excited some interest in Great Britain at the time of its partial publication, and which still is talked about

and looked for (not by the curious in such matters only) on the continent of Europe.

The piquancy of contributing to the re-appearance of a work, suppressed in the country where it originated, in another part of the world, and under the auspices of a State, singular in possessing a field of coal and iron ores and their ancillary deposites, not second to any or all of those which have created for England her commercial supremacy—would not have stimulated me to this task, had I not seen that the strongly practical and almost uniformly correct views of the writer were especially calculated to be rivetted in the attention and memory of those of my fellow-citizens engaged in the manufacture of Iron, who, without motive or leisure for pursuing the thread of a refined hypothesis, have abundance of both for reconciling and binding up in a general theory their every-day observations.

So, for instance, the idea, which will be found more fully developed in the Letters, viz: that *before you may make iron you must make glass,* is a position that, with many reflecting persons of the class I have mentioned, will place their daily manufacture in a new aspect; and so, the urgency of repetition with which is impressed the doctrine of *definite proportions* (in the principle that every element, however

minute, exercises in fusion its own proper attraction, absorbent or neutralizing) becomes a key, as it were, to unlock the mysteries and extricate from the embarrassments in which I have seen more than one furnace-administration involved.

The whole Treatise is so short as not to require any prefatory analysis of its contents, here; and the still shorter Appendix which I have added, contains only such new matter of my own reflection or research as seemed to me naturally or indispensably connected with the subject.

I had proposed adding to this document, statistical particulars of the manufacture, in Maryland, of Iron in the subsequent stages to which it is consigned from the blast-furnace. But although I have collected considerable material towards this end, its assemblage is too imperfect to allow of introduction into a document for reference: and I have therefore, with regret, been obliged to abandon my purpose.

Such incompleteness is not surprising, when we recollect how incommensurate to a considerable public aim must be the interest and industry of any single individual, unaided by a social sanction; and still less, when we see (as we may see) the inadequacy of an authoritative inquisition upon this and similar aims.

Of course, I allude to the last Census, etc. taken by authority of the General Government.

I would by no means be understood as criticizing that performance, either in its design or execution—in both aspects, I profess for it all the respect which becomes a citizen under that Government, and one who, having tried and trying (in another measure) the same experiment of collecting statistical information from masses of people, may be supposed cognizant of the peculiar difficulties which hinder it from giving exact results. With this, however, I may be permitted to say that, as far as I have means to judge, the Census does not represent the extension which this branch of industry has received in Maryland: nor is there any existing document that does.

In this view, I have pretermitted for the present all reference to the higher states of manufactured Iron, except where some particular in regard to them was necessary to illustrate the conditions of crude-iron: it is my design (if it be not inappropriate to speak here, in a public document and under such distinguished auspices, of individual intentions) it is my design to give to this subject of (so-called) wrought-iron, a place and a Report by itself. But in order to its being placed in its proper aspect, it is necessary as a preliminary, that reference should be had to re-

searches into the crystalline form of Iron under different circumstances, and to an investigation of the electro-chemical forces that are excited in Iron, variously alloyed, by exposure to a high temperature. It is obvious that only by an inductive theory, founded upon such research and investigation, can we arrive at the means of foreseeing and remedying the casualties which not unfrequently occur from an undue reliance on constructions of this metal, or at least of diminishing the risk which is daily accruing, one may say, to millions (on rail roads and steamboats, for instance) in its employment. Such means of prescience and prevention are, I venture to think, in a measure within our reach. Of the scientific interest or social importance which attaches to their attainment, I need not speak.

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A PREFACE being considered the explanatory address of an author, it is usually expected that he should therein elucidate his motives in attempting to attract attention.

With high respect, therefore, for the gentlemen embarked in the IRON TRADE OF GREAT BRITAIN, I submissively beg leave to state that my intentions are, to endeavor to point out by what means they may make iron, better and cheaper than is now usually done at Coke iron-works. And the attempt will, I presume to think, be entitled to the attention of those gentlemen, whom it is most particularly calculated to assist; although there is no doubt but that the means I have to recommend will, like all human projections, be found capable of great improvement.

I have endeavored to demonstrate the practicability of making equally as good iron with coke as with charcoal; and also with a species of ore which is at present rejected, when good iron is to be made.

And the cost of so doing will be less than that of the present common puddled coke-iron.

Iron-metallurgy has been but slightly examined in a truly scientific view; and, therefore, I shall think that I have accomplished a material point if I only make "the darkness visible," in which so important a manufacture is enveloped. But it will afford me no small gratification to see the subject, in abler hands, elucidated in the manner it is capable of being. Then will the more harmonious and admirable effects of genius and industry be substituted for the unnatural and devastating system of *force;* and every artist may then trace the causes of all his various results to their source.

This Treatise will suggest several new and important improvements in iron-metallurgy: particularly in the smelting of iron-cinders or slags (especially refinery-cinder) produced in considerable abundance and nearly a useless residuum at iron-works; and also of refractory iron-mines, and their conversion into perfectly good bar-iron—a difficulty not hitherto surmounted.

Professing to give an elementary Treatise, I have as little as possible interfered with manipulations;

processes are the paths from causes to effects, and caprice or fashion may pursue the road most agreeable to its fancy. I mean to lay down the *principles* of iron-making only, and shall endeavor to trace some hitherto unexplained effects to their causes, leaving the form and fashion of various apparatus totally out of the question.

In this Treatise, therefore, the mere practical man may find but little to afford him amusement; but the scientific, much for his reflection.

S. ROGERS.

AN

ELEMENTARY TREATISE

ON

IRON MAKING.

INTRODUCTION.

THE separation of Iron from its various combinations upon scientific principles has been hitherto little practised, and still less encouraged, in Great Britain. The processes employed are generally consigned to persons specifically appointed in different departments of the work. Many of these persons are very intelligent, clever and reasonable men, and many there are who are otherwise. The works over which the latter kind of men preside, will always be behind in the march to perfection; for it is a truth which is often remarked, that the Establishments at the head of Manufacturing concerns are always those which liberal-minded men are employed to conduct. Persons of this kind endeavour to shorten the way to really great and permanent improvements. The opposite kind retrograde as

much as possible from the never-erring footsteps of Science.

I have attempted in the following pages to lay down the outlines of a system for producing good Iron, in larger quantities, in a cheaper manner, and of a more uniform and better quality than is usually done at coke iron-works. The track I have pursued is, I believe, nearly unbeaten. I am therefore entitled to some indulgence: for he who proposes a new system may be considered somewhat in the light of a man who has to remove an old house before he can build a new one. Every body concurs in the opinion, that "pulling an old house about one's ears" is no enviable occupation.

It perhaps may be necessary to explain the theory I have pursued in this treatise. This I will do in as concise a manner as possible.

First will be considered the materials employed in Iron-smelting, as compounds of different kinds; and those compounds I have separated into their elementary particles. By this arrangement we have a synopsis of all the elements employed; and their future combinations may be then anticipated with an exactness obtainable in no other way. Any one element of the different compound bodies, I have considered identically of the same nature with a similar element in any other compound: for instance, oxide of iron is a compound of oxygen and iron—remove the oxygen and nothing remains but the

iron. It is upon such grounds I conclude, that as good iron may be made from one combination of which iron forms a part as from another. It is well known that charcoal produces better iron than coke, and scientific investigation ought to give the reason and point out the mode of obviating the difficulty. * *

The great desideratum in Iron-making is, to separate all the elements combined with the iron in the ores or cinder, from which we wish to obtain the metal. These various elements are all of them perfectly different, insulated atoms, which have the property of uniting and forming various compounds; and this inherent property is put into action either by the pressure of the atmosphere, by magnetic influence, or some other natural, though yet undiscovered cause, assisted by Caloric, Light, and contiguity. If this be the case, we have only to know what elements are to be operated upon, and withdrawn from their combination with the iron and with each other, to point out the additions necessary to attract all the various elements by a more powerful affinity than that which unites them with the iron and one another—producing new compounds with the additions made to effect this purpose. It is on this account that I so strongly recommend the complete and accurate analysis of all the different materials employed in Iron manufacture; for without such information, synthetical attempts to make good Iron

or good furnace-cinder will always prove irregular, and frequently abortive, and good materials will be blamed by improper and random applications.

The introduction of an active saline flux into Iron-metallurgy would have a most beneficial influence in producing good Iron or Steel; and in this respect alone, it has a claim on the consideration of those concerned in the Iron-trade. The addition of soda will have the advantage of saving both air and fuel—to say nothing of time and the improved quality of the iron. That something is wanting will be apparent from the following statement, viz:

To melt a ton of pig-iron requires about 1 barrow of coke; and as there is generally 2 tons of cinder to the ton of iron produced from a blast-furnace, we will suppose that 2 tons of cinder require for fusion 2 barrows coke; and to withdraw and saturate the oxygen of the iron will require 2 barrows more; and allow for several circumstances 1 barrow more, in all 5 barrows, which ought to make in the blast-furnace 1 ton of pig-iron: yet it usually requires 10 barrows coke to make a ton of iron. This circumstance therefore indicates some radical defect in the usual routine of Iron-smelting.[1]

[1] The radical defect noticed in the text, although sufficiently real, seems hardly to follow in strictness the premises which have been laid down for its result. For instance, the relations of the specific heats of the different substances, have been left out of view entirely. Without entering into long details, which neither the object nor place of this note call for, I will yet indicate the steps of a more proximate calculation on this point; as follows: the

It is probable that *fusibility* is all that is wanted to save one-half of the fuel required usually in blast-furnaces; and consequently half the air also. This would be no trifling consideration. For instance, an engine whose steam cylinder is 50 inches, or about 80 horse power, will blow 12,000 cubic feet of air per minute, at a pressure of 2 lbs. per square inch. This quantity of air will be sufficient to produce 25 tons of iron per day. If half the air, at half the density, (and density has nothing to do with the quantity of air driven into furnaces; the same quantity will always produce the same effect, density only gives velocity,) only would be required with the application of soda, an engine of the same power would produce 24,000 cubic feet per minute, and taking only ½ the quantity to the ton of iron, the same engine would give blast sufficient for 100 tons per day.[2] This subject alone has therefore no slight

specific heat of crude Iron we may take at 0.11, that of water being 1.; that of cinder is about 0.195, and that of protoxide of Iron 0.32. Their ratios are then 1. — 1.77 — 2.99. We assume 2 tons of cinder to 1 ton of crude Iron, and we may also assume the protoxide of Iron in the ferro-carbonates to be 45 per cent. and the quantity of ore producing 1 ton of crude Iron to be 3 tons: and we have then the following syntagm, expressing the heat necessary for the fusion of the materials:

$$(c)\ 2 \times 1.77 + (o)\ 3 \times 2.99 \times 0.45 = 7.58.$$

This represents correlatively the barrows of coke required; without any allowance for contingencies.

[2] This conclusion follows more logically from the premises than that mentioned in the last note; but the defect here is in the premises themselves, and in the inappropriate idea of density, as expressed in the text. If by "half the density," our author means ½ of the surplus elasticity of the blast above

claim upon Iron-masters. The saving of fuel however has a claim on the consideration of the community at large; for the aggregate saving of fuel in Great Britain would be nearly 1,000,000 tons annually.[3]

Chemical action is instantaneous, provided the substances are brought into actual contact, whether the quantities be the millionth part of a grain or thousands of tons. This circumstance points to the advantage that would arise from the *previous fusion* of the ores and fluxes. The materials would thus be brought into actual contact with each other; and as iron cannot remain in the state of oxide while in contact with carbon if the temperature be high, it would speedily be separated; and the other matters, if the flux be in due proportion, would form the desired glassy cinder, with a certainty and expedition never hitherto accomplished.

Such, therefore, are the grounds upon which I have built this treatise.

that of the atmosphere, his arithmetical results are inaccurate: if he meant on the other hand, that a blast of elasticity equal in totality to 8¼ lbs. per square inch, i. e. 13-30 more rarefied than the atmosphere, then both his chemical data were inaccurate, and his mechanical arrangements necessary for sustaining rarefaction more complicated and as difficult as those required for keeping up condensation.

On this subject of density, I have elsewhere expressed myself as particularly as the subject, in the present state of metallurgy, seems to demand. *See Report on Manufacture of Iron*, p. 238. ss.

[3] The present consumption in Great Britain of coal for the manufacture of Iron, cannot safely be set down at less than 5,000,000 tons annually.

1°. Good iron may be produced from any material of which it forms a part; because if the other matters be removed, nothing but pure iron would remain.

2°. Any compound of which carbon is the predominating ingredient, is as applicable to Iron-smelting as another; remove the foreign matters, and nothing but carbon will remain.

3°. All bodies having a tendency to combine in relation to their quantity and number, it follows that some mixtures are more fusible than others, in consequence of their constituent elementary atoms being in proportion better suited for true chemical union. Analysis, therefore, of the materials employed and produced in Iron-smelting, is the only true method by which the most advantageous combinations of the various elements can be discovered and synthetically produced.

4°. As all the various elements combined with Iron in the ores, and with Carbon in the fuels, are required to be separated, there can be no other means adopted than dissolving or attracting out the same; either by an addition of similar elements, so as to bring the whole into proportions best suited for chemical union, or by the addition of foreign active auxiliary matters that will do so. The introduction of Soda into blast-furnaces, will therefore be that auxiliary: for Soda is one of the most powerful fluxes existing, and as such, the advan-

tage of its introduction into Iron-metallurgy will be great.

5°. And lastly, chemical action cannot take place unless bodies are in actual contact. How many feet will pieces of ore and limestone descend in a blast-furnace, before they will melt and be brought into contact! Hence the reason why I recommend the previous fusion of the materials,[4] so as to bring them atom to atom, forming a homogeneous whole.

[4] This subject will be found more particularly treated of hereafter, in a special letter.

LETTER II.

IRON IN GENERAL — MATERIALS EMPLOYED — ORES, FUEL, LIMESTONE.

IRON is considered a simple element; and *good* or *bad* are terms, implying the greater or less quantities of other elements with which it may be united. Sulphur, carbon, phosphorus, arsenic, silicon, copper, lead, manganese, chrome and oxygen[5] have all been detected in combination with iron, injuring its quality more or less, in proportion to the quality and quantity of the alloying elements. It appears that iron acquires the name *good* when it has been nearly separated from the various earthy and metallic elements, with which it was combined in the earthy state, or may have become so while being converted into the state of malleable iron; and that it matters not from what combination, or by what means it has been obtained, the iron itself is equally good: it is the alloys only that degrade it, and that to a degree

[5] Berzelius and Berthier have warranted the conclusion that no oxygen can be present in the constitution of crude iron.

in proportion to their quantities.[6] The separation of those foreign ingredients, therefore, comprises the business of the Iron-master. His task is both expensive and laborious, and has hitherto been performed by main strength, science having been scarcely regarded. The time, however, is fast approaching, when scientific investigation will penetrate the obscurity which has for ages enveloped the most necessary and useful of all inventions, viz: the separation of Iron from its ores.[7]

6 It may be safely affirmed, that in fact the purity and isolation of the element of Iron referred to here is never attained—all the iron of commerce containing more or less mixture or alloy: indeed, the chemical element of Iron, which may be supposed nearly or quite found in our electrotypic process, is, in cohesion and several external characters, quite different from what we are accustomed to recognize as metallic iron. How far certain minute proportions of other elementary associations are necessary or suitable for conferring particular known characteristics upon the iron of commerce, is a question to which I have devoted and shall continue to devote some time, in order to its being demonstrated by a full series of analytic and synthetic experiments. The result of these experiments when complete will form another part of these contributions.

7 Since the period when the text was written, the anticipations here expressed have been gradually going on towards realization. The Annales des Mines, in France, and the Archiv of Karsten, in Germany, have attested uniformly the industry and frequently the talent and success of numerous contributors, whose interest and devotion are fostered to a greater or less extent by the different governments in both countries. Hence, in the midst of many local difficulties, the French and German establishments are able to compete with the more favourable position of their English neighbors, and in some instances to attain results denied to the latter.

It is to be hoped, that before long the American government may find reason to extend a moderate encouragement to the devotion of time and learning in this branch of knowledge and industry: whose scientific importance can only be measured by the magnitude of its practical results and its social and civic advantages.

The Materials required for iron-making are first, ores; secondly, charcoal or coke; thirdly, limestone or other fluxes; and lastly, oxygen or atmospheric air. The ores are compounds of iron, oxygen, silica, alumina, lime, sulphur, and magnesia, and frequently other metallic and earthy substances before enumerated as having been detected in combination with iron. To simplify the matter, we will suppose the ores to be compounds of iron, oxygen, silica, alumina, lime and magnesia. Charcoal and coke are also compound bodies; the former being carbon united with small portions of alumina,[8] silica, oxide of iron,

8 I note this passage principally to remark that, as far as I know, charcoal and wood-ashes contain *no alumina*. M. Berthier, who has already remarked the same thing, explains the absence of alumina by its insolubility in water and by the presence of stronger bases, such as Lime, Magnesia, and the protoxides of Iron and Manganese, fully combining with all the vegetable acids of the tree.

I have already in the former part of these contributions inserted some generalities on the composition of Wood. I may add here, from M. Berthier, the average constitution of white woods, seasoned: as under

Carbon, ...	38.48
Ashes, ...	1.
Water in combination, ...	35.52
Do. hygrometric, ...	25.
	100.

In charcoal, the earthy matters vary, according to the kind of Wood, and in proportion among themselves according to the soil producing it, from 1 to 5 per cent. They may be considered on an average as about 2.5 per 100.

A portion of them, varying, according to the Wood, from one-twelfth to one-fourth of the whole, is *soluble* in water. This soluble portion comprehends the alkaline salts; whose bases are potassa and soda, combined with carbonic, sulphuric and muriatic (and sometimes a trace of phosphoric) acids, and a little silica. This last substance, although in many plants and especially

potash, and sometimes minute portions of sulphur and phosphorus; the latter fuel is also carbon, more largely united with silica, alumina, lime and oxide of iron, but without potassa, yet it frequently contains magnesia, sulphur, phosphorus and sometimes arsenic.

Limestone is also a compound substance; generally consisting of lime, carbonic acid, silica, alumina, magnesia, oxide of iron, bitumen and water. Limestones containing magnesia in any material quantity should not be used, because of its refractory property which it communicates to the compounds into which it enters.

in the order of *grasses* it generally abounds, is rarely in any quantity in Wood. The remaining portion of the ashes is *insoluble* in water. It contains carbonic and phosphoric acids, silica, lime, magnesia and oxides of iron and manganese.

Such are the substances met with in Charcoal; and although their relative quantities are but very small, we know that practically some of them produce marked effects. I have not the space here to exhibit the details of their relations; which are however of high interest to be known by the scientific metallurgist. I shall only therefore refer to M. Berthier, Voie Seche: i. 262 ss.; where an extensive table of analyses will be found.

LETTER III.

AIR — ACTION OF THE MATERIALS IN FURNACES.

THE other substance, employed in Iron-making, far exceeds in bulk and weight all those before mentioned, and has hitherto escaped particular notice as regards its elements; I mean atmospheric air. This substance is a compound like the other materials, with this difference: the former are solid and inelastic dense bodies; while this is light in proportion to its bulk, and elastic beyond the power of compression by any human means to reduce it to a solid. Its elements are oxygen, nitrogen, hydrogen, carbon, sulphur (probably phosphorus,) and caloric.[9] For every cubic foot of ores, fuel and flux, that is thrown into the furnace, about 2,800 cubic feet of atmospheric air are introduced; and for every pound of the inelastic material there are employed $4\frac{1}{4}$ lbs. of the elastic.[10] This subject I shall however enter more minutely into as I proceed with these Letters.

[9] See Appendix A.

We are not yet justified in placing *caloric* among the list of appreciable elements.

[10] See Appendix B.

The action of these various bodies upon each other in the blast-furnace may be considered somewhat in the following manner, viz: the fuel in a state of incandescence decomposes the atmospheric air introduced, producing carbonic acid and probably carbonous acid [carbonic oxide] by an union of the pure carbon of the fuel with the oxygen of the air and a consequent disengagement of caloric; another portion of the pure carbon of the fuel unites with the oxygen of the ore, which then escapes as a gaseous combination of carbon and oxygen, leaving the iron in a metallic state, but blended and included in a net-work of half fused earthy residuum of the ores and fuel; and a further portion of carbon is disposed of, by a part uniting with the iron, (now reduced to a metallic state,) forming pig-iron or a compound of iron and carbon, which then becomes fusible at a much lower temperature than pure iron,[11] and thereby enabling it in some degree to disengage itself from its entanglements with the earthy matters, which, in this stage of the process, we will consider as in only a semi-vitrified state; a still further portion of the carbon becomes united with the elements of the water introduced into the furnace [combined with the solid materials and] in the

11 There is still uncertainty in the determination of the points of fusion of crude and malleable iron; which last is, I presume, meant by the expression of the text, *pure* iron. This subject has been already referred to, [*Part* I. *p.* 216, *note.*] In the Appendix C. will be found some additional particulars; whose statement would be too extended for a foot note.

state of vapor along with the atmospheric air, forming gaseous combinations of oxygen and carbon and hydrogen, and hydrogen and carbon. The latter combination in the state of gas contains an abundance of latent caloric;[12] the formation, therefore, of this compound gas may be considered as in some degree injurious, in consequence of the active caloric becoming latent, thereby reducing the temperature of the furnace, the medium by which the solid bodies become fluid.

I am inclined to believe that the clear glassy furnace-cinder when produced, has the property of dissolving or at least holding in suspension another and no very inconsiderable portion[13] of carbon. In this stage of the process, then, we will suppose all the carbon of the cokes to be disposed of, and the iron reduced to the metallic state and united with a small portion of carbon, forming pig-iron; putting

[12] These compounds not existing unaltered in proportion under ordinary circumstances in the liquid state, it is not so accurate to speak of their *latent* heat; which is strictly the heat of conversion into vapor. It may be presumed, that our author had in view the capacity of heat (specific heat) of the elements, when set free from their previous combinations. Thus hydrogen has a specific heat of 3.2936, that of an equal weight of water being 1: vapor of carbon of $(\frac{9}{6}\frac{4}{3}\frac{4}{3}\frac{4}{3})$ = 0.3163: light carburetted hydrogen $(\frac{9}{6}\frac{4}{3}\frac{4}{3}\frac{4}{3})$ = 0.4770. All these gases absorb, in the proportions stated, more heat than carbonic acid; and their existence is undoubtedly injurious to the temperature of the furnace: but their proportion is very small.

It may be questioned, if there is formed in the furnace any compound of oxygen with hydro-carbon.

[13] On page 197 of Part I. are assembled the results of nineteen varieties of cinder, in none of which has carbon been detected. See on the same point also p. 206.

all other alloys for the present out of the question. We then shall have all the remaining elements of the ores and fuel, (except oxygen and carbon,) left in a semi-vitrified state; which would in such a state not only envelope the remaining particles of iron and other materials, but in a very short time also impede the further introduction of a supply of atmospheric air, and occasion the consequent suspension of further operations. Limestone is therefore employed as a medium or flux to bring the said earthy residuums of the ores and fuels into liquid fusion; and the compound thus formed is a glass, more or less perfect in proportion to its elements and the existing temperature of the furnace.

LETTER IV.

ACTION OF MATERIALS CONTINUED — DIFFERENT RESULTS FROM THE SAME MATERIALS — NECESSITY OF COMPLETE FUSION.

THIS glassy cinder not only enables the small and almost imperceptible particles of Iron to subside, and then protects them from being oxidated by the air, but also assists to fuse the earthy matters of the fuel immediately before the blast; thereby presenting a clean surface of pure carbon to decompose the air nearly as rapidly as it is introduced, and consequently producing vivid combustion by the immediate disengagement of caloric, (the only essential purpose for which air is introduced into furnaces,) which may be considered the *primum mobile* in all metallurgical operations. Such appears to be the action and re-action of the elements of the different materials employed, during the working of an Iron-furnace. Carbon decomposes the air, producing carbonic acid and caloric; another portion of carbon reduces the iron to the metallic state; and a still further portion of the carbon unites with the iron, giving it considerable fusibility. The limestones unite with the various earthy residuums of the ore

and fuel, forming a more or less perfect glass or scoria. The iron, from its superior specific weight, sinks into the lowest part of the furnace, called the hearth, whence it is occasionally removed by the workmen, and the cinder floats on its surface, and as this accumulates beyond the quantity the hearth may hold, it flows away at an opening left for that purpose. This process appears to be easy of performance; and yet circumstances frequently arise, (and apparently without any cause) that, in the course of a few hours, alter the nature of the iron and cinder in such a manner as theory can have no conception of: the same materials, the same weight and measure of each, the same blast in density and quantity, the same workmen, and every iota the same, and yet without any visible cause, the results will be as different as if different materials and workmanship had been employed.

This invisible and apparently inexplicable cause I shall however endeavor to point out and remedy; and the principal requisite appears to be: to keep the fuel in the lower part of the furnace, as clean and free from thick semi-fluid cinder or scoria as possible, thereby, as before observed, presenting a surface of pure carbon to the blast; but to do so will require that all the earthy matters of the ores and fuel should, either of themselves or with the addition of limestone or other bodies, form a clear glassy cinder. When this is the case, the clear globules of

iron, as soon as they revive, are enabled easily to unite and subside. The cokes are, from the complete fusion of their earthy parts by the said liquid cinder, as fast as their carbonaceous parts burn away, presented in a clean and pure state to the influence of the rapidly decomposing air, generating and keeping up the supply of caloric, (the greater part of which caloric again becomes latent before it quits the furnace,) and the cinder itself easily flows away from the furnace. The iron in this case will be good, and the working of the furnace quite steady and uniform.

But when the earthy residuums of the ore, fuel and fluxes are in proportions that will not, at the temperature of the furnace, produce this liquid glassy cinder, then the cokes and the other materials in that part of the furnace where fusion and the separation of the iron first commence when the process is going on well, get enveloped in the half melted earthy masses, and are thereby protected from the influence of that portion of the blast that has escaped decomposition in passing through the lower part of the furnace; and the consequence is, such air becomes decomposed in a higher part of the furnace than it should be, giving out caloric sufficient to produce more pasty cinder, but not enough, even provided the various earthy residuums were in proper proportions to do so, to produce the clear liquid glassy cinder.

LETTER V.

LIQUID FUSION CONTINUED — FURNACE SCOURING — FURNACE IN GOOD ORDER — GLASS MUST BE PRODUCED — ANALYSES OF MATERIALS PROPOSED — ANALYSIS BETTER THAN ASSAY.

THIS half melted scoria again envelopes more cokes, and the air in consequence ascends higher and higher without decomposition and in quantity continually increasing, from the decreasing quantity of carbon in the lower part of the furnace, until at last a very large portion of the air originally introduced at the tuyeres escapes unacted on at the tunnel head.

Now, to return to the boshes or lower part of the furnace; the mass of cokes, being thus entangled and cemented together by the half melted scoria, form channel or chimney like passages, which get cooled by the wind, extending many feet (sometimes) in height, and producing what are generally called *long black tuyeres*. The blast now rushes through these passages in a nearly undecomposed state. The globules of iron, instead of being protected by the cinder, as they exude from the mass rapidly decompose the blast, and again become oxide of iron; this addition to the thick pasty cinder, causes it to

become very fusible, which, as fast as it is produced, (provided it escapes being solidified by the immediate action of the cold air, and thereby being added to the already formed black tuyere, or perhaps forming a fresh one,) flows down in a high state of incandescence, from a continuing oxidation of globules of iron, and the whole becomes a cinder, or more properly, a scoria, black, dense and brittle. A furnace in this state is technically termed *scouring*.

It therefore appears, that when the earthy elements of the ores, fuel and fluxes (after the separation of the oxide of iron) will only produce, at the temperature of the furnace, a thick pasty half fluid, half solid cinder,[14] she will invariably be doing bad work; and that it is only by the re-production of oxide of Iron (in consequence of the decomposition of part of the blast, by the protruding globules of metal entangled in the scoria) that the fusion of part of this glutinous mass is at all accomplished, and the absolute extinction of the combustion prevented. But on the contrary, when the earthy parts of the materials used in blast-furnaces are (after the iron and oxygen are separated, as before stated) in proportions that, at the usual temperature of the furnace, will combine and form a thin, clear, glassy cinder, which will keep the cokes perfectly free and clean, to instantly decompose the blast, and consequently keep up the requisite temperature of the furnace, and also

[14] Technically *tough*.

from its liquid and perfect fusion will allow the globules of iron to unite and precipitate, and afterwards protect them from being oxidated, and which will also itself easily flow in an uniform stream from the furnace, indicating the regularity of the process; then the furnace may be said to be in good working order, and good iron will always be made.

To produce a fluid glassy cinder is, therefore, the principal object of the Iron-master, but to do so it is, first of all, requisite that he should ascertain of what elements such a cinder is composed. This is a task which science will readily enable him to accomplish, and I conceive this to be the first step towards radically improving the art of smelting Iron-ores.

When he has ascertained the component elements of this good cinder, he will have some clue to the production of it synthetically, at any time. His next step should be to ascertain the elements of his ores, fuel and fluxes, then he will be enabled to apportion these bodies in such quantities as will, after the oxide of Iron is separated, leave a compound whose elements will nearly, if not quite, correspond with the proportions of the same elements in the said glassy cinder. His results will then be uniform and certain.

Many very clever men have pursued the assay, instead of analysis. To have done so is no reproach; but the assay only tells them that such ores contain such quantities of metal, and very frequently the

metallic part is one of the smallest of their elements. This may be satisfactory as far as regards the quantum of metal; but it gives no indication or information of the quantity, nature or number of the earths which require to be separated from it. The analysis on the contrary, informs us not only the quantity of metal in an ore, but also the quantity, nature and number of the earths, whereby data are given to calculate upon, which will ultimately lead through all the mysteries of analytical and synthetical chemistry.

LETTER VI.

TABLES OF MINES — GENERAL AVERAGE OF MINES — IRON-CINDER CONSIDERED — GRANULATION OF IRON-CINDERS RECOMMENDED.

WITHOUT obtaining the accurate analysis of all the various materials employed in blast-furnaces, the Iron-master will continue operating upon substances he has little or no knowledge of; and his processes must necessarily remain in the same uncertain state they now are in. These analyses will afford him true data to calculate the most favorable results; and there will be little danger of experiencing disappointment. These operations should be performed upon the dry and prepared materials, in the state in which they are introduced into the furnace, and the limestone I would recommend to be previously calcined.

When the different materials have been analysed, let Tables of their elements be made out; and as time and further experience may elicit improvements let corresponding corrections and alterations be made.

These tables to be formed somewhat in the following manner, viz: to make a table of mines, let it be

calculated what quantity of the different mines the work may produce.

But first of all it would be requisite to ascertain, how many kinds of mine there may be to calculate and operate upon. Suppose we say there will be three, viz: Ball, Pin, and Vein,[15] then let three or more analyses of each kind be taken, and an average of their elements made, and then a mean average of the different kinds again ascertained, thus:—

I. *Averaged Tabular Statement of* Ball *Mines—calcined.*

	BLACK.	GREY.	WHITE.	MEAN.
Oxide of Iron, ...	76.	75.	77.	76.
Silica, ...	16.	17.	15.	16.
Alumina, ...	6.	7.	5.	6.
Lime, ...	1.	1.	2.	1.33
Magnesia, ...	1.	0.	1.	0.67
	100.	100.	100.	100.

I must beg leave to remark, that the figures here introduced are merely employed to shew the nature and construction of the tables, and not as being the actual quantities of the elements of the different materials at any work; and also that it would be

15 These terms are not very common in America, though of almost universal acceptation in Great Britain. The beds of ore, besides this classification, are still farther qualified by some special epithets, which, no doubt, once had meaning in the original locality, but have long since lost it. *Balls*, are nodules of ore; small and flattened or elongated balls are termed *pins;* though the epithet arises more particularly from their mode of occurrence and quantity, than from their shape. *Vein* mine is so called, when the ore is continuously stratified. This bears also sometimes the name of *Band* mine.

utterly impossible to employ any set of figures to denote the proportions of elements of materials made use of at different works from the variations thence necessarily arising.

II. *Averaged Tabular Statement of* Pin *Mines—calcined.*

	BLACK.	BLUE.	WHITE.	MEAN.
Oxide of Iron, . . .	74.	72.	76.	74.
Silica, ...	16.	18.	17.	17.
Alumina, ...	6.	4.	5.	5.
Lime, ...	3.	5.	2.	3.33
Magnesia, ...	1.	1.	0	0.67
	100.	100.	100.	100.

III. *Averaged Tabular Statement of* Vein *Mines—calcined.*

	BLACK.	WHITE.	RED.	MEAN.
Oxide of Iron, . . .	70.	72.	74.	72.
Silica, ...	18.	20.	16.	18.
Alumina, ...	6.	3.	3.	4.
Lime, ...	3.	3.	6.	4.
Magnesia, ...	3.	2.	1.	2.
	100.	100.	100.	100.

These averaging tables being made out, it will then be required to know how much of each kind the work may produce proportionally, and then a general average may be taken of the elements of the mines. Suppose we say, that for every 5 tons of vein mine, there will be raised 3 tons of pins and 2 of balls, then the general table of mines will be as follows, viz:—

IV. *General averaged Table of* Vein, Pin *and* Ball *Ores—calcined: according to their respective working proportions.*

	VEIN ORES, 20 per ct.	PIN ORES, 30 per ct.	BALL ORES, 20 per ct.	MEAN.
Oxide of Iron, . . .	36.	22.2	15.2	73.4
Silica, ...	9.	5.1	3.2	17.3
Alumina, ...	2.	1.5	1.2	4.7
Lime, ...	2.	1.	0.3	3.3
Magnesia, ...	1.	0.2	0.1	1.3
	50.	30.	20.	100.

This will form the general table of mines, and any considerable variations in the quantity or elements of the different kinds may be easily corrected in making out the future tables.

The *cinder* produced in the refinery and puddling, the reheating and finishing processes, may be considered as ores of Iron from which it is desirable to separate the metal;[16] and therefore, similar tables to the above, of the elements of this species of ore, should be made out, and the quantities of each kind stated in the proportion in which they may be procurable.

But since there will occur considerable difficulty in keeping each kind of cinders by themselves, I

16 On reading this passage I presumed it (upon the information I had then obtained as to the date of the patent of Mr. Hill, mentioned in Part I. p. 61.) to be among the earliest public notices of the applicability of this material. I have since found Mr. Hill's patent to have been dated in 1814; that of Mr. Mushet, for the same purpose, in 1815. See Leuchs: *Das Neueste und Nützlichste der Erfindungen; Bd.* xix. *p.* 259.

would recommend the re-fusion of the whole that may be obtainable, in air or low blast furnaces, with the addition of limestone, mine-kiln dust, shale, clay or coal ashes, (taking care to make as uniform a mixture as possible,) and then to remove the liquid mass into water, which would completely granulate it, and deliver it in a state favorable for future reduction. An analysis of this granulated mixture should then be taken about once a month, and entered in a book under the general elementary table before mentioned.

LETTER VII.

TABLE OF IRON-CINDERS — ADJUSTMENT OF FLUXES — LIME-STONE CONSIDERED — ALUMINOUS LIMES.

But if the re-fusion and admixture of lime-kiln dust, shale and clay, or ashes, is not performed, then it will be required to have separate analysis of each kind of cinder, as before stated; and if the works should produce three distinct kinds, such as finery cinder, puddler's cinder and finishing cinder, and in the proportion of 5 of finery, 3 of puddling and 2 of finishing cinder, then make the general table of the elements of iron-cinders thus:

V. *General averaged Table of* Cinders *according to their respective proportions of employment.*

	FINERY, 50 per ct.	PUDDLER'S 30 per ct.	FINISHING, (*battitures*) 20 per ct.	MEAN.
Oxide of Iron, . . .	29.	20.	14.	63.
Silica, ...	17.	7.	4.	28.
Alumina, ...	2.	1.	1.5	4.5
Lime, ...	2.	2.	0.5	4.5
	50.	30.	20.	100.

This will form the general elementary table of the iron-cinders, which should accompany the before mentioned general elementary table of mines.

It is certainly very desirable that the mine-kiln and lime-kiln dusts, and the shales, and also fire-clay and common yellow clays, should each of them be analysed, and their elements arranged. The expense of doing so would be but trifling, compared to the advantage that may result from it,[17] particularly as these bodies will be required as auxiliaries in making out good cinder tables; therefore, the average proportions of elements should be made as follows, viz:—

VI. *Table of the Average Composition of Auxiliary Materials.*

	MINE-KILN DUST.	LIME-KILN DUST.	SHALE.	FIRE-CLAY.	COM. CLAY
Oxide of Iron,	18.	4.	15.	4.	6.
Silica, . .	36.	24.	34.	54.	58.
Alumina, .	20.	8.	28.	40.	31.
Lime, . .	16.	60.	21.	1.	3.
Magnesia, .	10.	4.	2.	1.	2.
	100.	100.	100.	100.	100.

These tables should follow those of the mines and iron-cinders and by that means they will be ready for future reference; and they may be termed tables of *diluting* or *adjusting fluxes.*

The *limestones* are next to be considered; and they should be most minutely examined, as their province in the blast furnace is to give fluidity to the earthy matters of the ores and fuel, which, otherwise,

[17] A great saving has been made in some works in Wales by following this advice in a small degree, but it has never been carried far.

would remain in only a semi-vitrified or porcellanous state. As it is probable that the perfect glassy cinder is a compound whose elements bear a relative proportion to each other, it follows that the limestones (either by themselves, or with the addition of some of the earthy matters last mentioned) should make that addition to the earthy residuums of the ores and fuel used in the furnaces as will produce a mixture, whose elements may nearly approach such relative proportions; the necessity, therefore, of strict examination into the limestone made use of is too evident to be slightly passed over.

The beds of limestone accompanying coal and iron-ores are stratified in great variety and number, (in S. Wales particularly); scarcely any two beds being alike in their component parts. A selection therefore should be made according as analysis may direct. It is too often the case that limestones are procured for Iron-works from the spot most contiguous to the furnace without any consideration as regards their component parts, and it does not unfrequently happen that good mine and fuel are condemned, and the produce of the furnaces deteriorated from employing a refractory limestone, because it is cheaply procured. Customs are not easily overturned, even when they are found to be notoriously bad; but truth and reason will ultimately prevail, because facts are unchangeable.

The limestone in which magnesia is found (if in large proportions) ought to be carefully rejected for furnace-work, as should also those in which silex greatly predominates. The beds of aluminous and siliceous kinds should be worked and left separate, and an analysis taken, and the results tabulated, and as accurate an average made as possible.

The averaging tables may be found thus,[18] viz:—

VII. *Table of the average Composition of aluminous* Limestone.

	DARK GREY.	WHITE HORNY.	BLUE HORNY.	MEAN.
Lime, [Carbonate of] . .	76.	76.	73.	75.
Silica, ...	8.	6.	13.	9.
Alumina, ...	12.	16.	11.	13.
Magnesia, ...	4.	2.	3.	3.
	100.	100.	100.	100.

[18] The Author has here, as in one or two other places, abruptly terminated his letter in the middle of a subject. I may remark here, once for all, that as Editor, I have not considered myself called on, or allowed even, to make such changes in arrangement as would be required to bring these Letters to that point, in a literary regard, where I would hold myself responsible for their artistical execution.

LETTER VIII.

SILICEOUS LIMES—ADVANTAGES OF SUCH TABLES—ANALYSIS OF COKE—TABLE OF COKE-ASHES.

THEN proceed in the same manner with the siliceous kinds of limestone, thus, viz:

VIII. *Table of the average Composition of Siliceous* Limestone.

	WHITE.	GREY.	BROWN.	MEAN.
Lime, ...	74.	76.	72.	74.
Silica, ...	16.	18.	20.	18.
Magnesia, ...	6.	4.	2.	4.
Alumina, ...	4.	2.	6.	4.
	100.	100.	100.	100.

These tables will be of essential service in enabling the furnace-manager to form his general mixtures in such a manner as will invariably produce uniform results. If he find his ores containing too large a portion of silex, he will, of course, employ a corresponding proportion of aluminous mines, while if the alumina should chance to predominate, the siliceous may be used.

The good glassy cinder often contains an excess of

lime which may be distinctly seen crystallized[19] in the lower or opaque part of the cinder, in atoms of all sizes, apparently suspended in the more perfect or glassy part. This excess of lime is, probably, no further injurious than in requiring a somewhat higher temperature for its fusion,[20] and the consequent lowering and also decreasing the extent of that particular situation in the furnace where the cokes are kept in a perfectly clean state by the complete fusion of the whole of their earthy matters; a circumstance that should be as much as possible guarded against, for the reasons before stated.

The analysis of *coke* should next be taken. This substance is generally used in blast-furnaces by measure; therefore 18 cubic feet (the barrows with which the furnaces in S. Wales are filled, being generally of that capacity) should be weighed, and then carefully burnt to ashes in a close stove or muffle, the ashes collected, dried and weighed, the

[19] A *crystallization* of the kind here spoken of, I have never observed. With coke-furnaces, an excess of lime produces what has been denominated a *lithoïd* cinder: the same relative circumstances in charcoal-furnaces, owing to increased fusibility from the potash, lead to a *vitreous* cinder, but without apparent crystallization.

[20] In regard to the limits of application of lime we are warranted in M. Berthier's conclusion, *Ann. de Ch. and Ph.* xxxiii. *p.* 154, of its utility in taking up the sulphur of the iron-ores of coal-regions. Lime combined with silica in atomic proportions, has a much weaker agency in this regard.

The infusibility of the cinder is the main limit to the application of lime: and this occurs on the one hand with equal quantities of oxygen in the silica and in the lime, and on the other when there is four times as much oxygen in the silica as in the lime. See Part I. p. 195. See also Appendix D.

difference then between the original weight of the cokes and of the ashes produced (making reasonable allowance for moisture) may be estimated as carbon. The whole should be tabulated thus:

Average weight of 18 cubic feet of cokes, . . .		450 lbs.
Weight of ashes after combustion, . .	20 lbs.	
Probable moisture, ...	10 "	
	—	30 "
Leaving the weight of carbon, ...		420 lbs.[21]

Here it may be necessary to remark that all combustible matters, except carbon, are put out of the question; for experience has demonstrated that cokes containing much sulphur or phosphorus are injurious,

[21] At some establishments in Wales the gross allowance for the barrow of coke is 420 lbs. leaving less than 400 lbs. of carbon. Generally the pure carbon may be rated at 85 per cent. of the gross weight of the coke. In Wales and in Maryland, this proportion would be nearer 95 per cent.; while on the continent of Europe, in Virginia, and near the Ohio, it will be found about 75 per cent.

With regard to the quantity of moisture, some experiments made by myself upon small pieces exposed for a short period to an atmosphere of steam, others to absorption from the ordinary atmosphere during a week, warrant me in stating the moisture absorbed to be from 0.5 to 3.5 per cent. of the weight of fresh coke. The difference seems to arise from the mechanical texture of the coke. I presume that the circumstance of there being, in the small pieces experimented on, more absorbing surface in relation to the mass than occurs in practice, is compensated by the quality of the pieces made carefully for my experiment. Their texture was very compact. By immersing a piece of fresh coke, a few degrees above the temperature of the atmosphere, in distilled water, the absorption was 22 per cent. of the weight.

If, in accordance with these deductions, we take the weight of moisture at 2 per cent. of the barrow of coke, the effect of such a proportion becomes worthy of notice, the whole quantity of vapor in 24 hours being about 630 lbs. nearly half as much as is introduced by a very damp blast.

and they have therefore been pretty generally rejected at blast-furnaces: accordingly, it is concluded that the cokes usually employed are only compounds of carbon and the earths before mentioned, and that it would be going too far into minutiæ and making the subject too intricate, to suffer such small quantities of matter, like the sulphur, phosphorus or arsenic found in cokes, (except the very worst kind,) to enter into elementary tables and consequent calculations of matters which, although confessedly injurious in bar-iron, are of little consequence in blast-furnaces. Pig-iron, as now made with cokes, is an alloy of many elements, and it is the after-process which must separate the alloying substances, and the more perfect the separation is, the better will be the bar-iron.[22]

To return, however, to the ashes produced from the barrows of cokes: we have 20 lbs. weight, and they may probably be a compound[23] of

Silica, . . .	6 lbs. or	30 per 100 parts.
Alumina, . .	5	25
Lime, . . .	4	20
Magnesia, . .	2	10
Oxide of Iron, .	3	15
	20	100

But perhaps the best way would be to form a table of elements of ashes of the several veins of coals

[22] See Note 6.

[23] Several actual analyses have been already given in p. 154, 157, of Part I.

from which the cokes used in the furnaces are made, (taking care to average them as fairly as possible,[24]) after the following manner:

IX. *General Table of the averaged constitution of* Coal Ashes.

	YARD VEIN.	RED VEIN.	WATERY VEIN.	FIERY VEIN.	4 FOOT VEIN.	MEAN.
Oxide of Iron,	15.	17.	13.	15.	10.	14.
Silica, . .	30.	28.	32.	30.	25.	29.
Alumina, .	25.	18.	22.	35.	40.	28.
Lime, . .	20.	26.	20.	14.	20.	20.
Magnesia, .	10.	11.	13.	6.	5.	9.
	100.	100.	100.	100.	100.	100.

[24] The average composition of the ashes of the coal of the Georges' Creek basin in Maryland may be taken as under, viz:

Oxide of Iron, . . .	45
Silica, ...	33
Alumina, ...	11
Lime, ...	11
Magnesia, *a trace* . .	–
	100

It is very probable, however, that the quantities in the text were found in actual analyses of coal in the neighborhood of Merthyr.

LETTER IX.

ADVANTAGES OF ANALYSING COALS — COLD-SHORT PROPERTY HINTED AT — AIR REQUIRED TO THE TON OF IRON.

THE ashes of cokes frequently regulate the use or disuse of particular veins of coal; this circumstance therefore points out the necessity of ascertaining the nature and proportions of their elements. By so doing, that substance which may, from its excess or deficiency, have been the cause of the rejection or only partial use of any particular veins of coal, will be detected, and then its bad effects with blast-furnaces may be neutralized, or so far corrected by the addition of elements that may be deficient, as to render it a fuel equal in value to any other veins that are considered good.

By the analyses of the ashes from the different veins of coal or (what would be still better) by a complete analysis of the coals themselves, it would be ascertained which vein would suit best for furnaces and fineries, and which for the reverberating fires, engine-boilers, &c. where neither the ashes nor the fuel come into immediate contact with the iron. A neglect in this particular may communicate qualities to the metal that would materially injure it,

such as causing it to become too *red-short* or too *cold-short*, qualities that have puzzled the most experienced iron-masters to account for. The fumes of bismuth instantly render gold brittle without any very perceptible addition being made to its weight, evidently indicating the quantity of the injurious body to be eminently small. The fumes of some volatile body in the flame of the reverberating furnace may communicate similar or other peculiar qualities to iron, causing it to become cold-short or red-short, (other probable reasons will, however, be hereafter considered, relative to these singular qualities,) and when once combinations have taken place, it is no very easy task perfectly to separate them. To strike at the fountain-head of such evils, should, therefore, be the main object of the iron-master; and an analysis of his coals will be the most likely means of obtaining the requisite information for this purpose.

I believe I have now enumerated all the dense and inelastic materials usually employed in smelting iron, and many may think it unnecessary to scrutinize into the other materials; but since there is among them a substance employed in such volumes, as well as in such very great weight, and upon the whole so absolutely necessary both in carrying away the great excess of carbon and generating the necessary supply of caloric, it would (I should conceive) be only half attempting the radical improvement of

iron-making, to neglect stating and calculating upon the elements of the atmospheric air required to produce one ton of pig-iron.

In coke furnaces it requires about 480 cubic feet of atmospheric air per minute, to make one ton of pig-iron per day, or a total of 691,200 cubic feet of air to every ton of pig-iron.[25] This air is usually driven into the furnaces at a density of 2 lbs. pressure on the square inch, or 288 lbs. upon every square foot, and its velocity is about 400 feet per second of time, or upwards of 270 miles per hour. Now, 1,000 cubic feet of atmospheric air weigh 75 lbs. at a mean pressure and temperature, and therefore the 691,200 cubic feet of air will weigh 51,840 lbs.[26] or upwards of 23 tons.

It is well known that the atmosphere contains

[25] Since the period when the text was written, several circumstances have contributed to lessen the consumption of air: so that it cannot be stated at more than 19 tons of air for the ton of iron, as already mentioned, Part I. pp. 168, 232. The number of cubic feet corresponding, varies of course with the pressure used. At 30 in. Bar. and 60° F. 19 tons would be represented by 556.340 cubic feet, very nearly.

[26] This entire paragraph can be more accurately stated by reference to the tabular values given on p. 240, Part I. Thus, with a pressure of 2 lbs. per sq. inch, the velocity of the blast is 458.3 feet per second, or upwards of 312 miles per hour. A cubic foot of air at the mean atmospheric density and temperature of 60° F. weighs 0.0765 pounds avoirdupois; and 1,000 cubic feet, therefore, 76.5 lbs. at a mean, and with a pressure of 2 lbs. per inch—86.5 lbs. very nearly: so that the 691,200 feet, if there were so many, would weigh 59,789 lbs. = 26.7 tons nearly.

The object in view will be, however, equally well answered by considering the numbers in the text as arbitrary, and in this light they are therefore retained.

several other gaseous bodies besides oxygen and nitrogen, which are considered as the only probable constituents[27] of pure atmospheric air, and carbonic acid gas and water in a state of vapor are looked upon as the principal impurities; but it is extremely probable, with the continual evolution of gases from decomposing bodies of all kinds, that a variety of gaseous bodies (besides water and carbonic acid) are diluted in the atmosphere. Supposing this to be the case, I will now proceed in my attempt to analyse the quantity required, in the general use of coke-furnaces, to produce a ton of pig-iron.

[27] See Appendix A.

LETTER X.

ANALYSIS OF ATMOSPHERIC AIR — IMMENSE QUANTITY EMPLOYED AT SOME WORKS.

FROM various experiments by several eminent philosophers, it appears that the quantity of carbonic acid gas in the atmosphere is either liable to considerable variation, or else that the actual quantity has not been accurately made out; for some have given it as high as 5 per cent., and others have stated it at not more than the one thousandth: however, suppose we estimate it at 2 per cent. by weight,[28] we then shall have in the 51,840 lbs. of air, 1,036 lbs. of carbonic acid. This compound is formed of 72 oxygen and 28 carbon, according to the apparently accurate experiments of Lavoisier, Allen and Pepys, and other philosophical chemists; but for the ease of calculation, as well as being more in accordance with the atomic system, I prefer stating the elements of this acid gas to be 3 of oxygen and 1 of carbon:[29]

[28] See Appendix A, for a rectification of this unusual mistake; which however, as the numbers are merely for illustration, I leave unaltered on the text. The true quantity here would be about 24 lbs. instead of 1,036 lbs.

[29] The author had possibly in view here the peculiarities in the compounds of carbon, when estimated according to volumes—peculiarities which arise from the hypothetical value which must necessarily be given to the specific gravity

by this statement we have, in the above quantity of carbonic acid gas, 259 lbs. of pure carbon and 777 lbs. of oxygen.

Water is dissolved in the atmosphere in various proportions; and many estimates have been given of its quantity. There is no doubt, however, but that temperature governs the actual quantity, and if we estimate it at 1 per cent. at a mean temperature, we shall not be much over-rating it; this will produce from 51,840 lbs. of air, say 518 lbs. of water, and if water is a compound of 85 oxygen and 15 hydrogen, we shall have in this 518 lbs. of water, 440 lbs. of oxygen, and 78 lbs. of hydrogen.[30]

The remaining impurities of the atmospheric air

of the vapor of carbon. Thus Dr. Turner estimates this vapor at 0.4215: Mitscherlich has given it at 0.8438; a quantity which I have used in a previous note. The composition of oxide of carbon and of cyanogen gas illustrates these peculiarities, a half measure of vapor of carbon entering into the former, according to the higher determination, and a whole measure according to the lower; while the latter is, by Mitscherlich, supposed to be made up of one measure of carbon-vapor absorbed by one measure of azote, but by Turner, of two measures similarly absorbed.

It is not impossible that in view of an habitual principle which may hereafter be more fully recognized, viz: that *when gases unite in equal volumes there is no condensation*, neither of these estimates are correct; but that the vapor of carbon will be considered as having a specific gravity of 1.2637—a determination which would tend to harmonize the mechanical laws governing the diffusiveness of gases and the, as yet, somewhat arbitrary alligations of volumes. It is obvious that in all these theoretical variations of combining volumes, the atomic relations of *weight* remain unaltered. The numbers, therefore, in the text which refer to weights, are erroneous. They are however left, as in other instances, for the reasons heretofore given.

30 See Appendix A.

Water, may be stated nearly enough at 89 oxygen and 11 hydrogen per cent. See Mitscherlich: *Chimie* i. 27, and *Ann. de Ch. et Ph.* xv. 395.

may, within the bounds of probability, be estimated at a thousandth part of the whole; therefore, in the said 51,840 lbs. of air, there may reasonably be computed, say 52 lbs. of casual impurities, exclusive of the carbonic acid gas and water. Those 52 lbs. may be compounds of oxygen, hydrogen, nitrogen, carbon and sulphur or phosphorus; and, if we estimate these elements in the following proportions, viz: oxygen 10, hydrogen 6, nitrogen 18, carbon 8, sulphur 8, and phosphorus 2; these united weights will form the above 52 lbs. of casual impurities.

Now, if we add together the weight of these various gaseous bodies, viz: carbonic acid 1,036 lbs., watery vapor 518 lbs., and the casual impurities 52 lbs., we shall have a total of 1,606 lbs.; then to obtain the actual quantity of pure atmospheric air, i. e. the due admixture of nitrogen and oxygen only, we must deduct this 1,606 lbs. from the gross weight of the 691,200 cubic feet or 51,840 lbs. before stated—the result will be 50,234 lbs., which must consequently be the weight of the pure air. This pure air being a compound of 3 parts nitrogen, and 1 of oxygen, (at least I employ these proportions for the reason before assigned, in stating the elements of the carbonic acid to be 3 of oxygen and 1 of carbon,) therefore the 50,234 lbs. will be composed of 12,558½ lbs. of oxygen and 37,675½ lbs. of nitrogen; so that the total elements of this said 51,840 lbs. of

atmospheric air may be considered as approaching the following proportions and quantities, viz:[31]

			totals.
Oxygen,	12,558½ lbs.		
Do. in carbonic acid,	777 "		
Do. in watery vapor,	440 "		
Do. in casual impurities,	10 "		
		13,785½ lbs.	
Nitrogen,	37,675½ "		
Do. in casual impurities,	18 "		
		37,693½ "	
Carbon in carbonic acid,	259 "		
Do. in casual impurities,	8 "		
		267 "	
Hydrogen in watery vapor,	78 "		
Do. in casual impurities,	6 "		
		84 "	
Sulphur,		8 "	
Phosphorus,		2 "	
Elements of 691,200 cub. feet of atmospheric air:		51,840 lbs.	

This large volume and weight of air being required, in coke furnaces with the present materials, to produce only *one* ton of pig-iron, it may appear surprising to persons not acquainted with iron-smelting how so exceedingly bulky a material could possibly be supplied; yet this wonder will most probably increase when they are informed that single establishments in S. Wales have engines of such power that they compress into the furnaces upwards of

31 This calculation and statement is very well as shewing the route of the investigation. Otherwise the quantities can hardly be considered an approximation of the fact. The constituents and their proportions of the atmosphere, as near as it is necessary for metallurgic purpose, have been previously given in the former part, p. 189.

50,000,000 cubic feet of atmospheric air daily, i. e. about 2,000 tons,[32] with a pressure of 288 lbs. upon the square foot at the lowest calculation, and a velocity, as before stated, exceeding 270 [310] miles per hour.

[32] The greatness of this consumption might almost tempt one to tremble for the equilibrium of the atmosphere, from which it is supplied. But vast as it is, when it comes to be multiplied by the number of similar establishments in Great Britain and elsewhere, it is yet nothing in the immensity of the provision of the earth-system, where it finds its resource. For instance, the whole weight of our atmosphere cannot be set down at less than 5,137 billions of tons; nor the oxygen in it at less than 1,181 billions. Now, taking the entire annual production of iron, on the face of the earth, at 8 millions of tons (which is one-half more than it really is) the yearly consumption of oxygen would be only about 13 millions of tons. And if we suppose that in all other manufactures and industrial pursuits, wherein oxygen is consumed, twice as much more is required, making in all, say 40 millions, we would yet find, upon calculation, that 300,000 centuries must elapse before all the oxygen would be destroyed.

In point of fact, the great department for the use of oxygen is in the support of animal life. If we suppose 1,000 millions of men upon the earth (which is at least one-fifth more than we have reason to believe actually exist) and consider the lower animals as equivalent to a daily consumption by 3,000 millions more, which is a current estimate—their joint conversion of this element might amount to about 1,500 millions of tons per annum; at which rate, however, 8,000 centuries must elapse before all the oxygen at present in the atmosphere would be used up.

We see then that with the exaggerated factors which we have attributed to the metallurgic consumption of oxygen, it is only about the one-fortieth as effective as the demand for keeping up the animal machinery; in which, as in all other engines where caloric is required, carbon is burnt. Both departments of expenditure, however, return what they have thus demanded to the atmosphere, and through that to the vegetable kingdom, in the shape of *carbonic acid*; to be decomposed by plants, which fix the carbon and liberate the oxygen again to go through its recurrent process. The respective productiveness in this regard is, if any thing, in favor of the furnaces; which, in a given time, yield a greater proportionate quantity of carbonic acid than animals are supposed to furnish.

LETTER XI.

SOURCES OF ORGANIC MATTER — TABLES OF AIR — WATER IN BLAST-FURNACES.

THE immense quantity of atmospheric air decomposed, and its oxygen converted principally into carbonic acid in all operations of fire, is a subject fraught with wonders.

Millions of tons of carbon, now lying dormant in the bowels of the earth, will, in process of time, by means of caloric, oxygen, hydrogen and nitrogen, become animated nature, filling the proudest cities with bustling inhabitants, clothing barren wastes with luxuriant verdure, and adding fresh tenants to the watery deep. The daily conversion of thousands of tons of carbon into an active and elastic gas, and the reversion of this gas into vegetation, and ultimately animalization,[33] is one of the sublime and awfully grand wonders of the creation.

To return, however, to the subject in question. Tables of the component parts of atmospheric air, at different densities and temperatures, would yield use-

33 This subject has been placed in a very striking light by M. Dumas, in a Discourse which has been recently published, and which has furnished or confirmed most of the particulars of the preceding note. An English translation of this Discourse has appeared in the L. & E. Phil. Mag. xix. 337, 456.

ful and valuable results; as they might possibly point out the necessity of increasing or decreasing the quantity of fuel required to produce any specific quantity of iron, according to the corresponding increase or decrease of the quantity of *water* introduced along with the blast.[34] Such water not only

[34] The detrimental effect in the furnace of the introduction of the vapor of water, by occupying valuable space or affording occasion for useless chemical changes, is not so easy to be calculated: but what may be termed the immediate *mechanical* effect, may more readily be approximately stated.

Thus, for instance, from the table in Appendix A, it may be assumed that during the period, from April to September inclusive, for every 1,000 cubic feet of blast employed in the charcoal furnaces of Maryland, there is introduced, upon an average, 1.21 lbs. of aqueous vapor, at a temperature of 57° F. And as those furnaces require, at a mean, 800 cubic feet per minute, we may take the whole weight of vapor introduced in 24 hours to be 1440 lbs., also the specific heat of that vapor may be taken at 0.847, that of water being 1. and that of iron 0.11. The sensible heat of the furnace may, in accordance with previous calculations (Part I. p. 248,) be taken at 3465° F.; and we assume that a temperature of 212° F. is to be imparted to the vapor before it either enters into decomposition, or is enabled by equilibrating the pressure of the atmosphere to pass out at the trundle-head, unaltered. These data arranged according to well known methods of calculation, give $\frac{1440 \times 0.847}{0.11} = 11{,}088$ lbs. as the quantity of iron that would be raised in temperature $212° - 57° = 155°$, by the same heat that would be absorbed in raising 1440 lbs. of vapor to a temperature of 212°; and farther $\frac{1440 \times 0.847 \times 155}{0.11 \times 3465} =$ 496 lbs. of iron raised to the permanent temperature of the furnace by the heat that is lost in converting the vapor of the blast into steam of elasticity equal to the pressure of the atmosphere.

If instead of the factor 3465°, the assumed standing temperature of the materials in fusion, we employ the number 2786°, representing the actual fusing point of crude iron (see Appendix C,) we have finally $11088 \times \frac{155}{2786} =$ 616.87 lbs. of iron that could have been melted by the heat wasted in the vapor.

Theoretically, these numbers (at a mean about a quarter-ton per day) represent the advantage in quantity produced by furnaces working in winter, above their summer yield. Practically, the difference is about a half-ton per day.

occupies space which should be filled with atmospheric air, but also requires large and useless extractions of carbon in order to neutralise its elements; consequently it is doubly injurious in blast-furnaces, and the only antidote appears to be an increased dose of carbon.

It is frequently imagined that the water thrown into the furnace along with the blast, and which in moist and sultry weather is very considerable and cannot be avoided, is repeatedly decomposed and recomposed;[35] but I am inclined to think the contrary, and that it is only once (and finally, as regards

[35] The decompositions and recompositions which go on *within* the furnace are at best obscure, and could only hereafter be expected to become inferential upon a sound inductive theory. At present, there is no necessity for supposing the vapor of the blast to be decomposed; since more aqueous vapor comes out amid the gases of the trundle-head than went in with the blast, (Part I. p. 191,) and it is partly upon this assumption that the calculations of the last note have been made.

Carefully conducted experiments might, however, afford us a direct proof upon this particular. Thus, if we assume the same data as just now, and farther that 1 pound of charcoal is capable of raising the temperature of 75 lbs. of water 180° (from 32° to 212°) we derive, by well known methods, $\frac{3408 \times 0.847 \times 1440}{180 \times 75} = 308$ pounds very nearly, as the quantity of charcoal that would effectuate the heating of 1440 lbs. of vapor from 57° to 3465°. This would be the extra-quantity of charcoal, required in 24 hours, to counteract what I have called before the mechanical disadvantages of the vapor of the blast. To effect chemical resolution and composition, however, on the assumption that the constitution of vapor is the same as that of water, there would be requisite in forming carbonic acid and carburetted hydrogen $\frac{8 \times 1440 \times 3}{9 \times 16} + \frac{1440 \times 6}{9 \times 2} = 960$ lbs. of pure carbon. To form oxide of carbon and olefiant gas would require still more charcoal. The difference in these quantities appears sufficient to absorb the errors of observation and to allow a determination of the question.

its oxygen) decomposed by the red-hot carbon of the fuel, forming carbonic [acid] or carbonous acid [oxide of carbon] and carburetted hydrogen gases: the consequent engagement of these portions of carbon reduces that substance to a minimum in relation [i. e. beneath its due proportion] to the other demands for it; so that a furnace under such circumstances works in the same manner and produces the same results as if it had been overburdened, or had too large a proportion of mine thrown in with a barrow of cokes.

The carburetted hydrogen is most probably decomposed either by the oxygen of the oxide of iron, thereby producing water and a carburet of iron, or by the oxygen of the blast, producing carbonic acid and water. In either case I consider it by no means injurious: for carburetted hydrogen in a gaseous state is united with a large quantity of latent caloric, and so is the oxygen of the blast, and the union of these two gases producing water and carbonic acid must disengage nearly all their caloric, which will amount to a much larger quantity than if the oxygen gas of the blast were decomposed by the carbon of the cokes: and therefore what is lost by the decomposition of recomposed water, is exactly compensated by the heat again given out during such recomposition; for the only utility that the oxygen is of in a furnace is to give out heat, and whether such oxygen unites with the carbon of the cokes in the first

instance, or whether with the carbon of the carbureted hydrogen (originally from the cokes) and with the hydrogen also, it can make no possible difference, as there can only be disengaged the latent heat of the oxygen originally introduced into the furnace,[36] and there can be no more carbon carried off ultimately than the quantity sufficient to saturate the elements of the water that may be thrown into the furnace. The reduction of the charge of mine, or what will amount to the same thing, an increased dose of carbon, is therefore the only antidote to a blast laden with moisture.

[36] Although it may be admitted as a fact, that, in general, the union of combustibles with oxygen is the source of sensible caloric and that the quantity of oxygen so united is a measure of the heat disengaged, it is nevertheless to be borne in mind that the epoch at which such union takes place is of considerable consequence,—theoretically, at least: or in other words, the same combustible elements (having reciprocal affinities) may, from time to time, be differently arranged in such wise as to produce different developements of heat by their respective combinations with oxygen. The illustrations of this subject are very interesting, both in theory and practice; but would be too extensive for a note.

LETTER XII.

BAD EFFECTS OF WATER NEUTRALISED — PERFECT *FUSION* DISCUSSED — ANALYSIS OF GOOD FURNACE CINDER RECOMMENDED — CINDER OTHER THAN GOOD TO BE ANALYSED.

If the quantity of water at these times introduced into the furnace was ascertained by analysis of the air, it would pretty accurately determine the increase of carbon which would be required to neutralise its injurious properties. For instance, suppose the air required to produce a ton of pig-iron did actually contain the before stated 518 lbs. of water, whose elements were 440 lbs. of oxygen and 78 lbs. of hydrogen, then the 440 lbs. of oxygen would require 146⅔ lbs. of pure carbon to become entirely carbonic acid;[37] but 220 lbs., if half this oxygen were converted into carbonous acid, (compound of 3 oxygen and 2 carbon,) and the other half into carbonic acid: also it would require about 117 lbs. of pure carbon (reckoning carburetted hydrogen to be a compound of 3 carbon and 2 hydrogen) to become [light carburetted] hydrogen gas. The amount of these two portions

[37] In the preceding notes I have given a calculation of the same kind upon more accurate quantities. Those in the text are altogether erroneous; as, for instance, carburetted hydrogen is a compound of 2 hydrogen and 6 carbon: but, for reasons already given, I have not allowed myself to alter them.

of carbon will be 337 lbs. Therefore, if one barrow of cokes contains 420 lbs. of pure carbon, *eight-tenths* of that quantity would be sufficient to neutralise the elements of the 518 lbs. of water; at all events, one barrow-increase on the quantity required to produce a ton of pig-iron would amply compensate for the introduction of such a quantity of water. If this increase of fuel is not applied, it will be required to reduce the charge of mine *one-tenth* upon each barrow of cokes. For instance, if the charge of mine weighed 500 lbs. and it required 10 such charges to make a ton of iron; then reduce the charge to 450 lbs. and nearly the same results will be obtained with 11 charges or barrows of cokes.

I have now enumerated all the materials employed in blast-furnaces; and from the various elements, the main object is to procure the iron united with a small portion of carbon. But this cannot be done, unless the earthy matters necessarily employed in the furnace are brought into liquid fusion; and the more this fusion of the earthy residuum approaches to clear and perfect glass, the better will be the iron, in consequence of the separation of all the earthy elements or semi-metallic alloys that would otherwise remain in, or become united with, the pig.

It is therefore essentially requisite that some data should be obtained, from which to calculate the proportions of earthy matters that will, after the separation of the oxide of iron, produce such a glass; and

the only probable means of doing so will be, first of all, to find out what are the component parts of a good, clear, glassy cinder, not only of one specimen, but of samples obtained from different works, made at different times, and produced from apparently different materials.[38] This would soon demonstrate whether such cinder were uniform in the proportion and number of its elements, and whether (as I am inclined to believe) such elements bear a relative proportion to one another. If such is found to be the case, there can be no doubt nor difficulty in synthetically producing such cinder at pleasure; and the fluctuations in the working and produce of the blast-furnaces will then immediately cease.

If the good cinder is a compound of the earths in any definite proportions, there will only be a difficulty to produce it when the mixtures employed in the furnaces are left to chance or bad management. Suppose, for instance, the good cinder to be:

Silex, ...	48
Lime, ...	32
Alumina, ...	16
Magnesia, ...	2
Oxide of Iron, . . .	2
	100

The proportions of silex, lime and alumina, (leaving out the magnesia and oxide of iron,) are then as 3 of silex, 2 of lime, and 1 of alumina, and

[38] See Part I. p. 197.

consequently they bear a relative proportion to one another, the lime being twice the quantity of the alumina, and the silex equal in amount to the other two.[39] However, let the proportions of the elements of the good cinder be what they may, it is absolutely necessary that they should be known, otherwise all attempts at synthetically producing it must necessarily prove abortive. The analytical table of the elements of this good, clear, glassy cinder, will therefore demand the unceasing attention of the furnace-manager in proceeding to apportion his general mixtures of ores, fuel and fluxes for the blast-furnaces.

It[40] would be very desirable that an Iron-master should know the component parts of his other furnace cinders, as the tawny and the black scouring cinder. An average table of their elements should be made out to accompany the other elementary tables, not as guides to the reproduction, but as beacons to mixtures that should be avoided; and in this respect they may be of more utility than can immediately be imagined, for avoiding bad mixtures will be approaching to improvements.

39 The proportions on the opposite page so nearly approach the true results, that they must have been taken from actual analysis. Generally, furnace-cinder may be supposed to consist of 1 atom of silica and 1 of lime united to a half atom of alumina and a quarter atom of magnesia. The oxides of iron, manganese and titanium, like sulphur and phosphoric acid, may be taken as accidental. This subject is more fully treated in the Appendix.

40 In the MS. this paragraph is placed at the beginning of the next Letter.

LETTER XIII.

TRIFLING INACCURACIES NOT WORTH NOTICE — GENERAL ELEMENTARY TABLE — GENERAL FURNACE MIXTURE.

THE next business I shall proceed with, will be making the general mixtures of ores, fuel and fluxes, for the blast-furnaces. The intricacies in forming them are, at first sight, considerable and perplexing; but a proper attention to the elements of the different averaged mixtures of mines and iron-cinders, and a careful selection of limes and of the diluting fluxes, (making due allowance for the ashes of the cokes,) will, with the elementary table of the good, clear, glassy furnace-cinder before mentioned, soon enable the proprietor to apportion his mixtures sufficiently near for practical purposes, with comparatively little trouble. For in blast-furnaces it will not be absolutely requisite to have precisely relative and definite proportions of the different elements to produce a good, clear, glassy cinder; because the high temperature therein generated, will make up for any little inaccuracy and resulting refractoriness on that account. Yet it is very desirable to obtain such a compound of the earthy matters of the various materials employed, as may become fluid and glassy at

a temperature but little higher than is required for the fusion of pig-iron.

Before we attempt the formation of a general furnace mixture, it will be desirable to make out a general table of the elements of the different averaged substances employed and also of the three kinds of furnace cinder, as before alluded to, thus:

X. *General averaged Table of different Materials.*[41]

PER 100 PARTS OF		OXIDE OF IRON.	SILICA.	ALUMINA.	LIME.	MAGNESIA.
Mines;	see Table IV. p. 35,	73.4	17.3	4.7	3.3	1.3
Iron-cinders;	ib. V. p. 37,	63.	28.	4.5	4.5	0.
Limestones (aluminous)	ib. VII. p. 40,	0.	9.	13.	75.	3.
do. (siliceous)	ib. VIII. p. 41,	0.	18.	4.	74.	4.
Lime-kiln Dust;	ib. VI. p. 38,	4.	24.	8.	60.	4.
Mine-kiln Dust;	ib. "	18.	36.	20.	16.	10.
Shale;	ib. "	15.	34.	28.	21.	2.
Fire-clay;	ib. "	4.	54.	40.	1.	1.
Common-clay;	ib. "	6.	58.	31.	3.	2.
Coal-ashes;	ib. IX. p. 45,	15.	30.	25.	20.	10.
Cokes; besides *Carbon* 93.4 and *Water* 2.2	p. 43,	0.7	1.3	1.1	0.9	0.4
Furnace-cinder; glassy,	p. 62,	2.	48.	16.	32.	2.
do. tawny,	. .	4.	36.	15.	41.	4.
do. black,	. . .	10.	36.	12.	30.	12.

Now, with this general elementary table before us, suppose we attempt to form a mixture for the blast-

[41] I have permitted myself to alter this table a little in shape, from what it is in the original manuscript; by omitting *two* columns, one of which headed *water*, was entirely blank, and the other headed *carbon* contained a single item referable to the cokes, which, and more, I have included in the letter-press of the table. Farther, as regards the cokes, the proportions which are in the original expressed upon the "barrow or 450 lbs. of cokes, measuring 18 cubic feet and containing 420 lbs. of carbon," etc: I have converted into proportions *per cent.* in order to be symmetrical with the other items of the table.

furnace. It is, however, necessary that I should state that in these calculations I have considered oxide of iron as composed of 7 parts of iron and 3 of oxygen.[42] These proportions are, perhaps, not quite accurate; but they will suit very well to shew the nature of the system I wish to propose, and I must leave it to the Iron-masters themselves to form elementary tables according to the various materials and proportions of the elements contained in them: To proceed—

XI. *Table for Mixtures.*

	IRON.	OXYGEN.	SILICA.	ALUMINA	LIME.	MAGNESIA
100 pts Mines averaged,	51.38	22.02	17.3	4.7	3.3	1.3
100 " Iron-cinders,	44.1	18.9	28.	4.5	4.5	0.
100 " Mine-kiln dust,	12.6	5.4	36.	20.	16.	10.
40 " Alumin's limes,	0.	0.	3.6	5.2	30.	1.2
20 " Siliceous limes,	0.	0.	3.6	8.	14.8	0.8
	108.08	46.32	88.5	35.2	68.6	13.3

Now, if we consider the parts [in the above table] to be tons, we shall have about 108 tons of iron from this mixture; and if it requires 10 barrows of coke

42 These proportions are those of the sesqui-oxide. But in the English and Scottish Iron-works as well as those of Maryland, by far the largest amount of the ore used is from a carbonate of iron; whose base is the *protoxide* of iron. The constitution of the protoxide, according to the same view here taken, would be 7 parts of iron and 2 of oxygen, or decimally, 77.78 iron and 22.22 oxygen per 100. When the brown hæmatites are employed, the previous roasting drives off a portion of the oxygen: And it is only when the *red* hæmatites are used raw (as is done in minute proportions of a charge, in Staffordshire, for instance,) that the proportions of the text would hold good.

to produce 1 ton of iron, the above quantity of materials will require 1,080 barrows, and this quantity will produce nearly 10 tons of ashes, which must therefore be added to the other materials, thus:

XII. *Table adjusted.*

	IRON.	OXYGEN.	SILICA.	ALUMINA	LIME.	MAGNESIA
Quantities from Tab. XI,	108.08	46.32	88.5	35.2	68.6	13.3
10 parts Ashes from the fuel, . . .	1.05	.45	3.	2.5	2.	1.
	109.13	46.77	91.5	37.7	70.6	14.3

In this mixture we have about 46¾ tons of oxygen; and to convert this quantity into carbonic acid will require a little more than 15½ tons of carbon [or 17½ tons according to the real constitution of carbonic acid:] but the 1,080 barrows of coke contain 202½ tons of pure carbon, being an excess of 187 tons beyond the quantity required to reduce the oxide of iron. This subject I shall however discuss hereafter.

LETTER XIV.

FURNACE MIXTURES ADJUSTED — ANOTHER FURNACE MIXTURE — MIXTURE CORRECTED.

Now, if we examine this mixture, we shall find the earths remaining, after the separation of the oxide of iron, in the following proportions, viz:

Silica, . . .	91.5 parts.
Lime, . . .	70.6 "
Alumina, . .	37.7 "
Magnesia, . .	14.3 "

We see, they bear no relative proportions whatever to each other. Therefore to bring them to do so in the manner before stated, (as far as regards the silex, lime and alumina, the earths which usually predominate in iron-furnaces,) we must calculate either from the silex or from the alumina; thus, if from the silex, we must say: here are 91.5 of that element, and we shall require *two-thirds* of that quantity, or 61 lime, and *one-third*, or 30.5 alumina, to form a relative proportion of 3 silex, 2 lime and 1 alumina. But in the above mixture we have 70.6 lime and 37.7 alumina: consequently there will be an excess of 9.6 lime and 7.2 alumina; and to adjust these and bring them into their relative

proportions, there must be an addition made of 4.8 lime and 21.6 silex: or else it will be necessary to reduce such portions of the original mixture as will make it less, by 7.2 alumina and 9.6 lime. But if we calculate from the quantity of alumina in the general mixture, then we must say: 37.7 alumina will require *twice* the amount, or 75.4 lime, and *three* times the amount, or 113.1 silex; but since we have only 70.6 lime and 91.5 silex, we shall be deficient 4.8 lime and 21.6 silex, to produce the aforesaid relative proportions: which deficiency corresponds in amount to the addition found necessary in the calculation from taking the quantity of silex first.

These proportions of 91.5 parts of silex, 70.6 of lime and 37.7 of alumina may be considered as differing too far from the desired relative proportions to make a trial of such a mixture in the furnace. We will therefore make a second attempt, keeping the mines and iron-cinders in the same proportions, and only varying the limes and diluting fluxes: thus,

XIII. *Trial Table for Mixtures.*

	IRON.	OXYGEN.	SILICA.	ALUMINA	LIME.	MAGNESIA
100 pts Mines averaged,	51.38	22.02	17.3	4.7	3.3	1.3
100 " Iron-cinders, .	44.1	18.9	28.	4.5	4.5	0.
50 " Mine-kiln dust,	6.3	2.7	18.	10.	8.	5.
50 " Siliceous limes,	0.	0.	9.	2.	37.	2.
10 " Ashes of fuel,	1.05	0.45	3.	2.5	2.	1.
	102.83	44.07	75.3	23.7	54.8	9.3

In this mixture the earths, after the separation of

the iron and oxygen, and excluding the magnesia, will be in these proportion:

Silex, . . .	75.3 parts.
Lime, . . .	54.8 "
Alumina, . .	23.7 "

But still they do not bear a relative proportion to each other in the manner before stated: therefore, let us proceed to find out what elements may be deficient, or what in excess. To do so, suppose we commence our calculations from the quantity of silex: and then we have 75.3 parts of that element, and we require to form the said proportions 25.1 parts of alumina and 50.2 of lime. In this mixture there are only 23.7 alumina; consequently we shall be deficient 1.4 parts of that element; but we have already 54.8 lime, and therefore here will be an excess of 4.6 lime. Now, if we calculate the proportions from the quantity of alumina in the gross mixture, we must proceed thus: 23.7 alumina will require 47.4 lime and 71.1 silex, in which case we shall have an excess of 4.2 silex and 7.4 lime. This mixture may therefore be considered sufficiently near the requisite proportions for trial in the furnace; and if the results should not prove satisfactory, the mixture may be adjusted by the addition of 3.7 alumina and 6.9 silex, if we estimate upon the preceding calculations from the quantity of lime on the gross mixture; or we may take from the original

mixture its excess of 4.6 lime, and increase the deficient quantity of alumina by 1.4 parts of that element. In either of these cases we shall obtain the aforesaid relative proportions of 3 silex, 2 lime and 1 alumina; and if the good cinder be a compound of the same elements in these proportions, there can be no doubt but that such a mixture as above, will, at any time, under the same circumstances, synthetically produce it.

LETTER XV.

MIXTURE FOR ONE BARROW OF COKE — THIS MIXTURE ADJUSTED — MAGNESIA NOT CALCULATED — BINARY AND TERNARY COMPOUNDS.

BLAST-FURNACES are usually charged with cokes, mine and fluxes, in the following proportions, viz: 1 barrow containing 18 cubic feet of cokes, 450 lbs. of mine, and 150 lbs. of limestone. Now, although the quantities of mine and limestone vary, the barrow of cokes is always adhered to. Suppose, therefore, we attempt a general mixture of the mines and fluxes requisite for 1 barrow of cokes; or, as it is usually denominated, *one charge*.

XIV. *Mixture for* one *Charge.*

	IRON.	OXYGEN.	SILICA.	ALUMINA	LIME.	MAGNESIA
200 lbs. Mines averaged,	102.76	44.04	34.6	9.4	6.6	2.6
270 " Iron-cinders,	119.07	51.03	75.6	12.15	12.15	0.
100 " Alumin's limes,	0.	0.	9.	13.	75.	3.
20 " Ashes of fuel,	2.1	0.9	6.	5.	4.	2.
	223.93	95.97	125.2	39.55	97.75	7.6

In this mixture we shall have

Silica, . .	125.20 parts.
Lime, . .	97.75 "
Alumina, . .	39.55 "

Yet still we have not got our established relative proportions; and therefore we must again proceed to calculate. If the alumina be the datum we commence upon, we have 39.55 parts of that element, and we shall require 79.1 lime and 118.65 silex to form the due relative proportions; but we have got 97.75 lime and 125.2 silex already, evidently then there will be in this mixture an excess of 18.65 lime and 6.55 silex. But, as the lime in this excess is nearly treble the amount of the excess of silex, I am inclined to think that such a mixture would produce the required good cinder. If, however, it should not do so upon trial, it may by the addition of 9.3 alumina and 21.4 silex be brought into the before given relative proportions.

In these calculations, I have rejected the magnesia, not because I consider that substance of no consequence as regards its proportion to the other elements, particularly as regards the fusibility of the whole; but in general (except when magnesian limestones are used) magnesia is in much smaller proportions than the other three earths, and while its quantity keeps below *half* the amount of alumina, I consider little or no injury would arise from its admixture. Perhaps it may in small quantities be even beneficial; for compounds are, in general, the more fusible in proportion as their elements are more numerous,[43] provided these elements are in gradative

[43] See Part I. p. 196, 202.

proportions in the order of their fusibility. Tables of the fusibility of mixtures would be of incalculable advantage to the Iron-master; for his business is *to make glass*, before he can procure the iron from his ore. Therefore, suppose we lay down a table, or rather a skeleton of a table, of different compounds; and let the operator enter the result, when performed, stating the time it may require for complete fusion of such compounds, or the complexion of the mass after (say 20 minutes) application of any particular temperature.

Table of Compounds of Lime and Silex.

QUANTITIES.	RESULTS.
1 Silex + 1 Lime:	[Very difficult of fusion, scoria translucent.
2 Silex + 1 Lime:	Fusible; scoria white, porcellanous.
3 Silex + 1 Lime:	Fusible; with highest heat, a porous glass.
1 Silex + 2 Lime:	Partially fusible; part remaining pulverulent.
1 Silex + 3 Lime:	Infusible.
2 Silex + 3 Lime:	Partially fusible.
3 Silex + 2 Lime:	Fusible; scoria scratches glass.
4 Silex + 3 Lime:	Difficult to fuse. This characterizes all.]

Tables [similar to this one[44] should be made] of compounds of lime and alumina, lime and magnesia, and again of silex and alumina, silex and magnesia,

44 In point of fact, this is the only one that can be given in practical detail; and I have therefore, from Descostil and Berthier, filled up its side of results. The presence of silica is essential to the fusibility of the binary combinations of the earths named; but the compounds of *silica and alumina* do no more than soften and agglutinate, and the most favorable proportions of *silica and magnesia* are only partially fusible. As for the combinations of alumina, lime and magnesia, two by two,—all such are *infusible*.

and also of alumina and magnesia: these would embrace the *binary* combinations.

Then should follow tables of *ternary* mixtures: thus:

Table of Compounds of Silex, Lime and Alumina.[45]

QUANTITIES.	RESULTS.
1 Silex + 1 Lime + 1 Alumina:	Fusible into a white glass.
2 Silex + 1 Lime + 1 Alumina:	
3 Silex + 1 Lime + 1 Alumina:	Fusible; the most so in pottery.
3 Silex + 2 Lime + 1 Alumina:	Fusible, into a porcelain; with a little oxide of iron or of manganese, into a dark glass; the scoria of blast-furnaces.

[Similar tables of silex, lime and magnesia,—silex, alumina and magnesia,—and lime, alumina and magnesia, will contain the particulars of the ternary compounds.]

45 In the manuscript, this table is set down in numerical terms to a great extent: but as it professes to be only for illustration, I have not thought it necessary to insert the whole. I have added in three cases the practical results of experiments, where they happened to fit in with the proportions given. Other particulars on this subject will be found in the Appendix.

LETTER XVI.

OTHER COMPOUNDS RECOMMENDED — KNOWLEDGE OF ELEMENTS REQUISITE TO PRODUCE GOOD CINDER — ACTIVE FLUX REQUIRED — HIGH HEAT OF FURNACES CHIEFLY REQUISITE FOR FUSING THE EARTHS.

AFTER the tables of ternary compounds, it will be desirable to insert combinations of silex, lime, alumina and magnesia. This table would be capable *of* great extension, and may not be absolutely essential; yet a knowledge of a few of such mixtures would be highly desirable.

Other mixtures may also be made, by introducing portions of barytes, strontian, soda and potash; and their respective results should be tabulated. Such information might lead to useful and valuable discoveries in the separation of the earths in iron-smelting; for a total separation can never be effected unless the whole be in a state of liquid and perfect fusion.

To return, however, to the subject: these furnace mixtures may be varied almost *ad infinitum;* and it will only be required to ascertain the elements of combination that will produce the desired good cinder, to be able always to produce the same at any time, for nothing is more certain in nature than the

invariable action of material bodies upon each other under the same proportions—a difference in the result only demonstrating a difference in the original mixture of the elements. To obtain a knowledge of such a mixture, as will be a perfect glass at the temperature which may be required to fuse iron, should be the principal aim of the Iron-master; his attention therefore should be unceasingly directed to procure this requisite information: for, except the earthy matters of the ores, fuel and fluxes, are brought into a thin glassy fusion, he never will be able to separate the iron; and as the temperature at which this earthy residuum enters into fusion, will always depend upon the proportions of its constituents, a deficiency or excess in either of the elements may greatly retard the fusion of the whole.

If these earthy matters could be brought into fusion at a lower temperature than they now are, it would not require so large a quantity of fuel, air, or time to produce a ton of iron; but to effect this, will require the addition of some active flux along with the silex, lime, alumina, and oxide of iron.

If *barytes*, or *strontian*,[46] could be procured sufficiently cheap and abundant, there can be no doubt that the addition of them would have a most beneficial effect in blast-furnaces; but there appears, at

46 The silicates of these substances do not, by themselves, fuse at moderate temperatures: but, in multiple compounds, doubtless assist reduction. The supposed difficulty in smelting ores wherein the sulphate of baryta occurs, has of late been obviated. See Lampadius: *Neuern Fortschritte*, p. 157.

present, no hope of obtaining either of these earths in the quantities that would be required for iron-smelting. We must, therefore, search for other bodies that will make the earthy residuum in blast-furnaces, to run into liquid glass at temperatures lower than are now employed; provided such temperatures are sufficiently great for the fusion of pig-iron.

Cast-iron will melt and revive at a much lower heat than that generated in blast-furnaces: witness *assay-crucibles*, through which though bad conductors of caloric, the heat must penetrate to separate the iron by its fusion and subsidence, and to disengage it from its chemical union with oxygen and earthy parts of the ore. Yet the heat of assay-crucibles, I should think, never approaches half the temperature of the blast-furnace;[47] and the separation of the earthy matters of an ore in small crucibles (except under particular management) could never be accomplished, were it not for the assistance of active fluxes.

The intense heat of blast-furnaces is, then, only requisite for bringing the residuary earthy matters into liquid fusion, and not for the mere regeneration and smelting of iron. Fluxes, therefore, will save heat; and as heat requires air and fuel to produce it, consequently fluxes will save both air and fuel—two very expensive materials employed in iron making.

47 In *quantity* of heat, the weight is undoubtedly on the side of the high furnaces; but in *intensity*, not necessarily, nor even generally so.

LETTER XVII.

ELEMENTS OF CHARCOAL-ASHES — AIR AND FUEL IN FURNACES CALCULATED.

THE quantity of *charcoal* required to make a ton of iron, the product of ashes such quantities will yield, and the analysis of these ashes, would form a table of very great value to the coke-iron-master: for, by its means, such an addition of *potash* might be made to coke-ashes as to make them nearly as fusible as charcoal-ashes; which then would produce similar effects in coke-furnaces, (although, perhaps, not to so great an extent) and the iron produced therefrom would then approach the nature and quality of charcoal-iron, from the more perfect separation of the earthy residuum, etc. as before mentioned.

The quantity of atmospheric air required in blast-furnaces is governed by the quantity of fuel to be consumed or, more properly, decomposed: and the following calculations may probably throw some light upon the subject; for although not conclusive, yet they may be considered as laying down some data for future calculations.

In the usual run of coke-furnaces it requires (with few exceptions) 691,200 [500,000] cubic feet of

blast to produce one ton of pig-iron;[48] and this quantity of air is principally decomposed, by its oxygen forming carbonic acid with the carbon of the cokes and its caloric producing the requisite temperature in the furnace. Therefore, supposing all the oxygen converted into carbonic acid, and the acid a compound of 3 of oxygen and 1 of carbon; [more exactly, $2\frac{2}{3}$ parts oxygen with 1 part carbon = 1 part oxygen with 0.375 parts carbon] we shall have from the above quantity of air (which, according to the table of atmospheric air before given, contains $12{,}558\frac{1}{2}$ [9,948] lbs. oxygen,) about $16{,}744\frac{1}{2}$ [13,678] lbs. of carbonic acid, composed of 4,186 [3,730] lbs. of carbon and $12{,}558\frac{1}{2}$ [9,948] lbs. of oxygen. Now if it requires 10 barrows of cokes, containing 420 lbs. each, or a total of 4,200 lbs. of pure carbon to produce a ton of pig-iron, we should then after the decomposition of the blast, requiring 4,186 [3,730] lbs. of carbon, only have 14 lbs. of carbon [470 lbs.] left to unite with the oxygen of the ore; to say nothing of the other demands for carbon, as before stated. We may therefore rest assured, that the whole of the atmospheric air is not decomposed in passing through blast-furnaces.

The quantity of carbon being stationary, suppose we make calculations from this datum, and see how the amount of it is disposed of, allowing the air to

[48] I have enclosed, for the whole of this calculation, corrected quantities in brackets. See also *ante*, p. 48 and notes.

unite with the excess of carbon after the aforesaid abstractions are made from it, thus: 4,200 lbs. of pure carbon are required to the ton of iron, and to produce this quantity of iron will require about 3,200 [2,880] lbs. of oxide [the protoxide] of iron, composed of 960 [640] lbs. of oxygen and 2,240 lbs. of iron;[49] the oxygen of the oxide of iron will then, in becoming carbonic acid, take up 320 [240] lbs. of carbon: and the iron may probably unite[50] with 60 [75] lbs. more. The water in the blast, I before stated at 518 lbs.; but suppose we estimate it at only 200 lbs. [including the moisture of the cokes]: this being a compound of 170 [178] lbs. of oxygen and 30 [22] lbs. of hydrogen, there will be required 56⅔ [66¾] lbs. of carbon to form carbonic acid with its oxygen, and 45 [66] lbs. of carbon to neutralise its amount of hydrogen. And if, as I before expressed my belief in the case, the good glassy furnace-cinder dissolves a portion of carbon,[51] we must apportion a quantity for that purpose, and say 20⅓ lbs. for the amount of carbon, which is dissolved in the glassy furnace-cinder produced in making a ton of iron.

49 See note on page 66.

50 The mean proportion of carbon in crude iron may be stated at 3½ per cent. See Part I. p. 218.

51 See note 13 on page 23.

LETTER XVIII.

AIR AND FUEL CONTINUED — COMBINATIONS OF CARBON IN FURNACES — AIR UNDECOMPOSED — DENSITY REQUIRED.

Now, therefore, if we calculate up these different abstractions of carbon,[52] the residue must be the only quantity left to decompose the blast and keep up the necessary temperature:

	lbs.
Carbon required to saturate the oxygen of the oxide of iron,	320
Do. united with the iron in pig-iron, . . .	60
Do. do. oxygen of the watery vapor, . .	56⅔
Do. do. hydrogen of do. . .	45
Do. dissolved or suspended in cinder, . . .	20⅓
Total, ...	502

Here, therefore, we have 502 [640] lbs. of carbon to deduct from the quantity originally required to

[52] Assemblage may be made of more precise quantities, as under:

The oxygen of the ore may take up . .	240 lbs.	of carbon.
Do. in the vapor of the blast, . .	133	"
Do. do. with the cokes, .	80	"
The hydrogen do. of the blast, . .	132	"
Do. do. with the cokes, .	80	"
And the crude iron contains per ton, as a mean:	75	"
Making for the total, ...	640 lbs.	of carbon.

The quantity of carbon, that may be taken up by the nitrogen of the air and by the hydrogen and sulphur of the fuel, cannot be now stated.

produce the ton of iron, i. e. 4,200 lbs.; so that there will be 3,698 [3,560] lbs. of pure carbon left to unite with the oxygen of the blast.

Now to convert this quantity of carbon into carbonic acid, will be required 11,094 [9,493] lbs. of oxygen. In the table of air it is calculated, that 12,558½ [9,948] lbs. of oxygen are introduced into the furnace to produce the ton of iron; but, since there is only carbon sufficient to saturate 11,094 [9,493] lbs. of oxygen, it must necessarily follow that the difference between these quantities (which is 1,464½ [455] lbs.) will be the oxygen passing undecomposed through the furnace, for this evident reason, that it will find nothing therein with which to unite. These 1,464½ lbs. of oxygen will indicate 80,603 cubic feet of air; therefore, for every ton of iron that is made, there will pass through the furnace 80,603 cubic feet, or 6,045 lbs. of air undecomposed,—being nearly *one-eighth* of the whole air employed to obtain such a result. [Upon the corrected calculations, the surplus of oxygen (455 lbs.) corresponds in round numbers to 22,800 cubic feet or somewhat less than 2,000 lbs. of air; being only *one twenty-second* part of the whole blast.] This circumstance will, therefore, strongly corroborate the hypothesis before hinted at,[53] viz: that the cokes are entan-

[53] This is no doubt a proper inference; and serves to show a waste both of fuel and air. But its importance is much diminished, by the results of the more precise quantities which I have interpolated; and by which the useless excess of air is seen to be about 4½ per cent. of the gross quantity employed,

gled in a semi-fluid mass of the half-vitrified earthy elements of the ores, fuel and fluxes, and consequently protected from the direct influence of the blast.

I have, in the foregoing calculations, considered that portion of the oxygen of the blast which actually does undergo decomposition, and also the oxygen of the water, and the oxygen of the oxide of iron, as being totally converted into carbonic acid; whereby the quantity of carbon is made to go as far as possible: and I have not taken into account the oxygen and hydrogen of the casual impurities of the air, which would have abstracted a still further portion of carbon, and leave less for decomposing the blast.

If any portion of the carbon escapes from the furnace as *carbonic oxide*, this would indicate a still less quantity of air to have been decomposed: and it is not at all improbable that a very considerable portion of this compound of oxygen and carbon is actually produced; which with the gaseous combinations of hydrogen, as they escape at the trundle-head, enters into a final combustion by an union with fresh atmospheric air, and produces the peculiar flame exhibited at the top of blast-furnaces, causing all *deep-*

while the loss of carbon is only 4 per cent. of the quantity supposed actually necessary to make a ton of iron. Proper as the inference is, however, it is not in its direction that the great waste meant to be signalized in the text is to be accounted for. The modifications of mechanical arrangement consequent and even necessary upon the general employment of *heated air*, have as much as any thing else tended to reduce the consumption; which at the commencement of this century was thought moderate, but now would be deemed extravagant. See Part I. page 179.

red colors to appear purple, and rendering all *pale-reds* nearly colorless; a phenomenon always to be seen, but which has as yet escaped inquiry.[54]

The prodigious velocity with which the air is required to be driven into coke-furnaces, is another indication of the conglomeration of the cokes and the pasty, half-fused residuum of the ores. For, if it were not to be compressed into these kind of furnaces at a density of 2 lbs. pressure upon the square inch, or nearly so, it would never be able to penetrate through the materials; and long experience has convinced the Iron-masters (of South Wales in particular) that, with the usual-sized furnaces and [usual] materials, unless their pillar of blast will support a column of mercury of four inches elevation (which is about tantamount to the pressure above mentioned) the work performed will be irregular, and the furnace would be extremely susceptible of derangement.

54 Since this was written, not only has the supposition of the formation of carbonic oxide (and that to an extent, at a mean, quite as great as the production of carbonic acid) been proven; but the final combustion of this and other gases here spoken of as taking place at the trundle-head, has been, step by step, translated to another place, and applied to a most important economical use. The brilliant discovery of M. Faber-Dufaure (the principles of which, I may be excused for saying, were independently demonstrated in the former Part of these Contributions, and whose results, actual and anticipated, were, as far as I know, for the first time consigned to the vehicle of the English language *there*, too,) in economizing and burning these gases, marks the epoch of the most important revolution which has ever taken place in the manufacture and commerce of Iron. I propose in the Appendix to add some farther theoretical particulars regarding this subject.

LETTER XIX.

CHARCOAL-FURNACES AND COKE-FURNACES COMPARED.

It may not be amiss to compare charcoal and coke furnaces together, in all their points. Such a comparison may promote a useful purpose; and it is surprising to me that so little attention has been paid to this subject.

Coke-furnaces are usually from 40 to 50 feet in height, and from 12 to 16 feet in their largest diameter. They will contain about 5,000 cubic feet of materials; and the contents of one of these furnaces are worked off in from 40 to 50 hours. They require a blast whose density oscillates between 2 and 3 lbs. pressure on the square inch; and they usually consume about 691,200 cubic feet of atmospheric air (or 51,840 lbs.) and 10 barrows of coke, containing 18 cubic feet each, and weighing about 4,500 lbs. to produce *one* ton of pig-iron.

Charcoal-furnaces are seldom 30 feet in height, and frequently not more than 20 feet; their largest diameter from 5 to 8 feet; and their contents scarcely amount to 1,000 c. feet, which are generally worked out in from 20 to 25 hours. The density of the

blast required seldom exceeds a pressure of 1 lb. on the square inch; and frequently it is much less. It usually takes about 345,600 cubic feet, or 25,920 [28,305] lbs. of air and 20 bags of charcoal, containing about 12 cubic feet each, and weighing about 2,250 lbs.,[55] to produce the ton of pig-iron.

Now suppose we put these comparisons into a kind of table: it will be placing the subject in a better point of view for future reference.

	COKE-FURNACE.	CHARCOAL-FURNACE.
Height, . . .	40 to 50 ft.	20 to 30 ft.
Largest diameter, .	12 to 16 ft.	5 to 8 ft.
Cubic contents,[56] .	5,000 cubic ft.	1,000 cubic ft.
Worked off in . .	40 to 50 hours.	20 to 25 hours.
Density of blast, .	2 to 3 lbs. per sq. in.	¾ to 1 lb. per sq. in.
Air, per ton of Pig, .	691,200 cubic ft.	345,600 cubic ft.
Fuel, do. .	4,500 lbs.	2,250 lbs.

In the above calculations it must not be considered that the different weights and measures of the different materials, here stated, are those always actually employed; as very considerable latitude must be allowed for the varying nature of the different establishments. All that is now aimed at, is to lay down the skeleton of a system; and it will be the business of the proprietors of different iron works to make the actual calculations, when they have ascer-

[55] See Part I. pp. 171, 179. Some further particulars are in Appendix B.

[56] The quantities here are greatly over-rated in both cases; probably from an erroneous mode of making the calculation.

tained by analysis the quantities and proportions of the elements upon which they are to operate.

Charcoal-furnaces, it appears, stand in this relation to coke-furnaces, viz: they are generally about one-half the elevation—half the diameter—one-fifth the capacity—work off their contents in about half the time—require blast of one-half the density and only half the quantity of that blast, and half the quantity of fuel to produce one ton of iron.

Now, according to this account, charcoal-furnaces produce results far more advantageous than are ever obtained in coke-furnaces: for, it appears, that a ton of iron is produced with one-half less fuel, and one-half less air at one-half less density, than is usually required in coke-furnaces. Such amazing advantages are well worth inquiring into; and as there can be no effect without a predisposing cause, let us endeavor to trace out the cause of this singular and very desirable effect.

LETTER XX.

CAUSE OF SUCH ADVANTAGES — DIFFICULTY IN PROCURING THE MEANS — A SUBSTITUTE PROPOSED — EXPENCE.

CHARCOAL-ASHES, as I before observed, contain *potash* along with other bodies; and this potash disposes the other bodies to enter readily into fusion, forming a perfect glass. This glass, when formed, exerts a very considerable solvent power over the earthy matters of the ore, assisted by the limestone therewith; and the whole soon becomes a thin, liquid, and perfect glass. The iron, easily and speedily separating in a metallic state, is protected by the liquid cinder from being oxidated, because iron from its superior specific gravity will always be undermost; and the carbon of the charcoal is presented to the blast in a clean and pure state, fit for immediately decomposing the air. No part of the furnace, then, is impeded by half-fused, pasty masses of the earthy elements of the ores, etc. (unless bad work is being performed; and thick, imperfect fusion only takes place, which sometimes occurs also in charcoal-furnaces, when the earthy residuum is in such proportions as will not, at the temperature generated, form a perfect glass) and when this clean

and vivid combustion takes place, the rapid reduction of the iron and liquid fusion of the earthy matters consequently follow.

It therefore appears extremely probable, that the superior work performed in charcoal-furnaces is in a very considerable degree owing to the potash contained in charcoal; and if, as I before hinted, an addition of potash was made to coke-ashes (or to the cokes themselves) so that it should be in the same proportion to the other earths as may be found to exist in charcoal-ashes, there are good reasons for supposing that similar effects would be produced in coke-furnaces, viz: a ton of iron would be made with less fuel, less air and of less density, in less time, and of much better quality.

The quantity of potash that may be required for this purpose would, however, too much enhance the price of pig-iron, for it ever to become of any thing like general use, even were it to be procured in sufficient quantity; the introduction, therefore, of this valuable flux into large iron-works is as hopeless as the obtaining of barytes or strontian.

There is, however, another material of equal value (if not superior power) as a flux; to be procured in abundance sufficient to supply any demand, and at a price that will not exclude it from introduction in iron-smelting. This is *muriate of soda*, or common salt; an inexhaustible store of which, is within the reach of every Iron-master in the kingdom: and

there is no doubt but that the Legislature of the country would allow the conversion of sea-water into a flux for iron and copper smelting, without interference, under proper restriction. This would be, in a national point of view, of vital importance; because more and better iron could be procured with the usual materials, and the iron trade of Great Britain would never have to contend against quality with any nation upon earth.

A flux made from *sea-water* may be obtained for about two shillings per Cwt.; and if two Cwt. of the flux were to be employed to the ton of bar-iron, the advantages resulting would be ten-fold the additional expense. This quantity of flux would introduce into coke-furnaces more soda[57] to the ton of iron than

57 The quantity of soda here proposed to be used is unnecessarily large; for the silicates of soda are even more fusible than those of potassa. In the ashes of charcoal we may allow *one-half* in weight to be potassa; or keeping the potassa and soda together (usually not separated in the analysis) we may rate the alkali at *five-eighths* of the ashes. Now these ashes, at a mean, do not exceed 2½ per cent. of the weight of charcoal yielding them. At this proportion, the potassa would be 1¼ per cent. of the fuel; and taking the charcoal for one ton of crude-iron, as stated before, to be 2,250 lbs. the quantity of potassa contributing to the production will be not more than 34 lbs. On the other hand the 200 lbs. of sea-salt, proposed to be applied, will contain at a mean 97 per cent. or 194 lbs. of chloride of sodium; corresponding to $\left(\frac{23.3 \times 194}{58.7} =\right)$ 77 lbs. of pure sodium, equivalent to 103.4 lbs. of its protoxide or *soda*. If the 2 cwts. of the text are rated at 224 lbs. the difference would be still greater, and the quantity of soda would exceed 5 per cent. of the crude-iron produced. Reckoning this quantity, however, as applicable to all the processes up to the finished bar, it is not theoretically much in excess; although in any one of the practical applications which have been made of common salt (especially in fineries) I know no case where the proportions have

there is of potash in the charcoal that is required to make a ton of charcoal-iron, and therefore, it is not unreasonable to expect that results somewhat similar to [those of] charcoal-furnaces may be obtained in furnaces wherein coke is the fuel employed. The cokes would be kept in clean and vivid combustion by having their earthy matters fused into a perfect glass, and their pure carbon presented immediately to decompose the blast; the temperature of the furnace would be kept uniform and active; the iron would be rapidly reduced to the metallic state and united with its dose of carbon: and the whole of the earthy elements of the different materials employed would be speedily converted into a perfect and fluid glass.

Furnaces under such circumstances would invariably produce good results, and be very little liable to interruptions or derangements. Such advantages are, therefore, within reach of the Coke-iron-masters of Great Britain; and it will be their own fault if they do not embrace them.

exceeded the *fifth* part of what is proposed in the text. In regard to the utility of these applications and the value of the suggestion itself, although since the publication of the former Part of these Contributions I have heard of several fortunate instances, I may refer to (without repeating) what I said then. See Part I. p. 148. See also Lampadius: *Neuern Fortschritte*, p. 188. I will only add, that the well-known volatility of common salt is likely to superinduce, in its employment as a flux, a loss of metal (volatilized with it) to be discounted from the saving of fuel in the fusion taking place at a lower temperature. Whether the metal lost is worth more or less than the fuel gained, is a question to be determined for each individual case. See Berthier: *Voie Seche*, i. 498.

LETTER XXI.

PRODUCTS FROM THE BLAST-FURNACE — PIG-IRON.

We will now return to the blast-furnace, and conclude the operations therein gone through and the resulting products: i. e. *pig-iron*, *furnace-cinder*, and the various *gaseous compounds* which escape at the trundle-head.

These different products, like what were originally employed, are compounds of a number of elements; and it would be very desirable to get at the knowledge of their different constituent parts. Actually to do so with all three distinct products is, perhaps, too difficult to be ever accurately performed:[58] but *two* out of them may be atomized without much trouble, and the third may be attempted analogically.

The first to be considered is the *pig-iron*.. This compound substance, although it contains so great a preponderance of one element, (the iron,) yet the inferior portions exert so powerful an influence over the natural welding and ductile properties of the

58 In the first Part of these Contributions, I have presented some analyses of all these products; though, especially with regard to the gases, not so extensive as could be desired. See Part I. pp. 197, 218, 259. Also, for additional analyses of crude-iron, see Lampadius u. s. p. 169–174. L. & E. Phil. Mag. xiii. 429, 517, 576.

iron, that it retains few of the indicative peculiarities of wrought-iron, except specific weight and magnetic polarity. The different bodies which neutralise the properties of the iron are, at present, [1819] only guessed at; for mere inspection is the only method taken to ascertain, even in the most extensive Iron-works, the qualities of pig-iron. So inaccurate a mode of getting at facts will however, it is hoped, be soon abandoned; since the light of Science illuminates a more certain, safe, and fairer road.

The elements of cast-iron, [crude iron] from the nature and variety of the different materials employed to produce it, as well as the more or less perfect performance of the blast-furnace operations, must be as various and irregular as any thing possible to be conceived; and therefore nothing but an accurate analysis of it will give the desired information as regards its component parts. But here again I must beg leave to remark, how utterly impossible it would be to insert a single analysis that should even nearly approach the amount of elements to be found in pig-iron of different qualities, at the same works, to say nothing of the varying nature of pig-iron at different establishments; and therefore the following calculations, as well as the preceding analytical tables, must be considered only as the outlines of others to be filled up by the proprietors of the different works themselves, with the results of actual analysis of their own materials. But to proceed:—Cast-iron [crude-iron] is usually made up (as it

is supposed) of the following elements, viz: iron, carbon, some of the earthy impurities of the ores, fuel and fluxes, and also some sulphur. This last substance is the imagined deteriorater of all the operations of iron-making; from the raw material to the finished bar. If any thing is the matter in the blast-furnaces and the fuel is suspected, it is sulphur in the coals; other veins of coal are tried and still the results are the same, then it is the mines that are sulphurous; change the mines, and still sulphur does the mischief: sulphur has blame in the finery, sulphur takes the fault in the puddling, and sulphur gives all the bad qualities to the finished bar. This kind of argument is, however, conclusive on one point; it bespeaks the very superficial information possessed as to the real degrading bodies combined with iron in any stage of its progress, from the ore to the horse-shoe. Sulphur, of course, like carbon, will mix with iron; but also like carbon, will separate readily from iron: and the same operations that separate carbon will, in general, separate the sulphur also.

The concluding pig-iron to be only a compound of iron, carbon, sulphur, and some of the earthy impurities of the materials employed to produce it, I shall endeavour to rectify, and to point out the existence of other bodies from analogy; because, I think, this is a much fairer method of reasoning than stating imaginary facts, when so many real difficulties are in the road to get at them.

LETTER XXII.

PIG-IRON CONTINUED—EARTHY ADMIXTURES—SULPHURETS—CARBURETS.

In the first place it is now generally considered that metals will not chemically unite with an oxide, nor of course with earths of any kind; and therefore if a [simple] metal should contain an oxide, or an earth, it is merely suspended or mechanically dispersed through it like fine particles of earth suspended in muddy water. This hypothesis is not merely conjectural, for many instances of the fact may be obtained.

The oxidation of metals immediately alters their specific gravity; and consequently, while any metal is in a fluid state, its oxide will rise to the surface of the mass.

If this fluid metal, with its film of oxide upon its surface, were agitated or poured from one vessel into another, it is reasonable to suppose that part of the oxide may mix mechanically with the metal, like earth would with water; but rest would allow the lighter impurities to rise to the surface of the metal and the heavier or earthy impurities to fall to the bottom. But since the liquid cast-iron, in a blast-

furnace, has little or no time for subsidence, it naturally follows that part of the oxide may mechanically entangle and disperse through the mass of metal. Also, when cast-iron is tapped from the blast-furnace and while running from thence into the pig bed, part of the iron will oxidate by decomposing the water of the moistened sand; and this oxide rolling along with the metal will become more or less blended therein, and the fluid metal soon solidifying prevents the mechanical separation, by rest, of the suspended oxides, which then apparently become part of the iron. This will in some degree account for the earthy impurities to be met with in cast-iron; but it is a mere *mechanical* mixture, and one of easy and perfect separation, and totally differing from a true *chemical* union.

This mechanical mixture of oxide could not (in the proportion found in cast-iron) render it brittle nor in any way injure the welding quality of the iron; for many puddled-bars contain visible grains of sand and oxide, in as great (if not greater) proportions than pig-iron, and yet they possess welding and ductile properties. To convince any one of this, let him polish a piece of puddled-bar and a piece of cast-iron; and he may then satisfy himself of the greater mechanical mixture of sand and oxide in bar-iron. The brittleness of cast-iron therefore, it is fair to conclude, does not arise from the mere ad-

mixture of sand, earth or oxide; and we must look elsewhere for the cause.

Sulphur, as I before observed, is generally considered an injurious mixture for iron; and the fragile nature of cast-iron is often attributable to this substance. Now when iron is united to sulphur, it forms what is termed a sulphuret of iron; and if the iron is in excess, it forms what is called a sub-sulphuret. This sub-sulphuret of iron is of less specific gravity than cast-iron; and therefore it will in part separate like the earths and oxide, and part may remain mechanically suspended in the metal, and a part may also, very probably, become chemically alloyed with the iron. The same operation, however, that will separate the carbon (as mentioned above) will get rid of the sulphur; and I conceive it no more injurious, to render iron brittle or non-weldable, than an equal quantity of carbon. It therefore appears probable, that sulphur cannot be the substance which causes cast-iron to become brittle and to differ so widely from bar-iron. Now, according to the supposed original elements of pig-iron, we have no other substance left but carbon; and therefore let us examine the combinations of iron and carbon, and see how far they may destroy the welding and ductile properties of iron.

Cast-steel is considered a compound of iron and carbon; and this substance can scarcely be welded: but still it has considerable ductility, and it ap-

proaches more and more to the nature of wrought-iron, in proportion as the quantity of carbon decreases. Carbon, therefore, causes iron to become in some degree brittle; but yet it does not destroy its ductility, except when in very great excess. It would, therefore, be desirable to ascertain the quantity of carbon in steel, and also the quantity in cast-iron:[59] and it would likewise be well to know in what state the carbon is with the iron in the combinations—if it be a mere mixture of carbon and iron, or rather a carburet of iron dispersed through the mass of pure iron and carbon.

59 The mean proportion of carbon in crude-iron has been already stated (p. 81, *note*) at 3¼ per cent.; in *blistered* steel, the proportion is about 1¾ per cent. and in *cast* steel not more than 1½ per cent.

LETTER XXIII.

TWO CARBURETS OF IRON — DIAMOND, METALLIC CARBON — OTHER ALLOYS.

Now, it appears that *white cast-iron* is an alloy of iron and carbon, in which the latter substance forms but a small portion of the whole: this, I shall term the sub-carburet of iron; and the carbon in the compound I consider as chemically alloyed, atom to atom, with the iron. This one well defined compound of iron and carbon, is of a homogeneous silvery white color. The substance called [graphite] *plumbago* or black lead, is an alloy of iron and carbon, in which the latter element considerably predominates; this I shall consider the super-carburet of iron.[60] What is termed best foundry-iron, or

[60] These were the doctrines held, with more or less distinctness, by every one until the discoveries of M. Karsten: and as they are sufficiently plausible in the scarcity of analyses (of which the text has so uniformly complained) it is not surprising that our author should have adopted them. At present, *white* crude-iron, the lowest carburet of the text, is recognized as united with more carbon than any other kind of manufactured iron; while *graphite*, although no specimen has been observed entirely free from iron (the proportion of the Borrowdale mines is at a mean 2½ per cent.) yet holds that iron in the state of oxide—as a mere mechanical admixture, and is therefore properly regarded as, chemically, carbon only. For farther particulars see Part I. pp. 208, 212, 220—225. Mitscherlich; *Elemens de Chimie*, i. pp. 83, 84.

dark-grey pig, is a compound of these two carburets, in which the white color of the sub-carburet is overcome by the darker and more brilliant color of the super-carburet or plumbago.

There is every reason to think, that these carburets of iron are merely blended together in foundry or grey pig; and not, that such pig is an homogeneous compound of indefinite [varying] portions of iron and carbon. There is an intermediate species of cast-iron, which very visibly indicates such compound to be a mere mixture of the two carburets, and which is termed *mottled pig:* here, the whole ground of the sub-carburet is distinctly seen, sprinkled with beautiful crystals of the super-carburet; which, in my mind, removes any doubt about the defined nature of the two carburets of iron.

The sub-carburet of iron is of less specific gravity than iron itself; and the super-carburet is again much lighter than the sub-carburet: so much so, that rest would allow nearly the whole of the super-carburet to rise to the surface, were the iron to remain long in a fluid state. Carbon appears, therefore, to have nearly the same effect upon iron as sulphur or oxygen; i. e. it unites with it and forms a compound of less specific weight than iron: but the carbon in the carburets is chemically united with the iron, and therefore in a state of combination quite different from the mere mechanical mixture of the earths or oxide, as before stated.

Now, I mentioned above, that metals will not chemically unite with an earth or oxide; therefore, it is fair to conclude, that the carbon in union with the iron in the carburet, is not in the state of earth or oxide, but in the actual metallic state, or in the state of absolutely pure carbon: and, as the diamond is considered carbon in its greatest purity, it is nothing more than probable that carbon united with iron is in the state of *diamond*, and that diamond may be considered carbon in the metallic state. This alloy of iron and diamond possesses the peculiarity of most other alloys, viz: that of being brittle and fusible; although its constituents are not so, at least as far as concerns the diamond. This peculiarity always occurs when two metallic bodies are chemically combined, and is therefore an additional reason for concluding the carbon in carburet of iron to be in a perfect metallic state.

It would not only be desirable, but it is actually necessary, to determine the quantity of carbon that neutralises the welding property of iron and produces what is termed cast-steel; and also the quantity which forms common steel, which is both ductile and weldable, like pure iron; and also the quantities which constitute the two carburets before mentioned. This would show the inaccuracy of concluding the brittleness of cast-iron to arise from the carbon; for the sub-carburet most probably does not

contain as much carbon as steel,[61] and yet steel retains all the welding and ductile properties of iron, and its tenacity is even very considerably increased, witness the strength of steel wire. And again, when pig-iron has been refined and even passed through the puddling-furnace and most probably all the carbon is separated, yet still it will remain brittle and what is termed *cold-short;* and this, therefore, cannot arise from the carbon. Moreover the sulphur and earths mechanically blended with the pig-iron or finer's-metal, are no doubt nearly separated at the same time the carbon is got rid of; therefore, there must be some other cause than what has been mentioned hitherto, to make cast-iron so brittle, and unfit for purposes to which wrought iron is applicable. To trace this effect to its source will require a continuance of analogical reasoning; and I hope satisfactorily to demonstrate the existence of other alloys of iron, which are produced, in the usual manner of working coke-furnaces, in very considerable quantities, and which unequivocally communicate the brittleness or cold-short property to iron.

61 See note 59, on page 99.

LETTER XXIV.

DEFINITE ALLOYS — SILICIUM — ALUMINIUM — CALCIUM — SILICIUM, THE PRINCIPAL ALLOY.

I HAVE in the foregoing remarks considered the term *alloys*, in a general sense, to imply the union of different metallic bodies in indefinite proportions; except alloys of iron and carbon in the two carburets before stated, which I am inclined to think are *definite* proportions of iron and carbon, and not the mere union of the two metals only. For instance, iron, copper and zinc I consider as a triple alloy, the three metals forming a homogeneous whole; and again, iron, copper and lead,—iron, zinc and manganese,—iron, manganese and copper,—all form true alloys because the metallic bodies are united atom with atom[62] and no particles of either will be distinct from the whole, nor separable by any mechanical power.

[62] As an illustration of what I have elsewhere called "a very judicious comprehension of the aim and application of the science of chemistry" on the part of our author, I may here quote the cautious sentences of the late Dr. Turner on the very subject here treated of. "Metals appear to unite with one another in every proportion, precisely in the same manner as sulphuric acid and water. It is certain, however, that metals have a tendency to combine in definite proportions. It is indeed possible that the variety of proportion in alloys is rather apparent than real, arising from the mixture of a few

Such is the nature of alloys that are operated upon at Iron-works; and from which the iron is required to be obtained as far as possible. It is therefore of the first consequence to ascertain the metallic bodies which may thus be alloyed with iron, giving it (in the state of cast [crude] iron) the brittleness and fusibility peculiar to almost all alloys. Copper, lead, zinc, manganese, and other metallic bodies may sometimes be found alloyed with iron; but instances are so rare that I will conclude they do not occur to any extent that is injurious. We must therefore look round for some other metallic bodies, which probably do unite with the iron in the pig and give it the characteristic brittleness of alloys.

Now, if we recapitulate the elements of the materials which are employed in blast-furnaces, we shall find no other metal suspected than iron, the other elements being silex, carbon, alumina and lime; puting magnesia out of the question. Here then is the field for further inquiry.

definite compounds with each other, or with uncombined metal; an opinion, not only suggested by the mode in which alloys are prepared, but in some measure supported by observation. Thus, on adding successive small quantities of silver to mercury, a great variety of fluid amalgams are apparently produced; but, in reality, the chief, if not the sole, compound is a solid amalgam which is merely diffused through the fluid mass, and may be separated by pressing [the mechanical power of the text above] the liquid mercury through a piece of thin leather." Turner: *Elements of Chemistry;* p. 398. Sixth Am. Edit. The reader may also find interest in the observations of M. Rudberg upon the thermometric determination of the epochs of definite alloys; to which Dr. Turner has likewise referred: *Ann. de Chim. et Phys.* xlviii. 363.

The carbon, I have concluded to be united with the iron in the state of diamond, forming a true chemical alloy of iron and diamond; but then carbon does not (in small proportions) cause the welding and ductile properties of iron to become latent.

The metallization of the earths,—silex, lime and alumina, must therefore be the source from whence iron becomes alloyed; and this is the more probable, since an analysis of pig-iron will generally exceed in the amount of products the weight of iron employed, and there always will be a residuum of the earths before mentioned, particularly of silex; and this increase of weight it is not unreasonable to suppose arises from the absorption of oxygen by these metallized earths upon their dissolution in an acid. Silicium, aluminium and calcium may therefore confidently be expected to be alloyed with iron and carbon in pig-iron.

The eminent discover of these semi-metals has left no doubt of their reality, and I shall not hesitate in considering the earths, silex, alumina and lime to be of as certain reduction into their respective metals as oxide of iron, oxide of copper, or any other metallic oxide, and therefore I shall treat them accordingly. Corresponding with this hypothesis, pig-iron will be an alloy of iron, carbon, silicium, aluminium, and calcium; in which as the quantity of aluminium and calcium are in general very minute, I will discontinue naming them, and consider that silicium

alone is the injurious alloy of iron. The same reasoning will hold good and the same operations will separate the two former semi-metals from iron as well the silicium; but it will be simplifying the process to consider the alloying substance to be silicium only: therefore in this case pig-iron will be an alloy of iron, carbon and silicium, in which alloy are suspended some oxide and earths, but which oxide or earths have no chemical union whatever with the alloy, and from which they are easily separable, or at least their quantity will be in the refining and finishing processes so far reduced as to be very little detrimental to bar-iron.

It appears to be the silicium therefore which causes the brittleness of cold-short iron,[63] and it will have this property, more or less, according to the quantity of silicium with which it may be alloyed. The separation of this semi-metal is then the only difficulty to be overcome to produce iron of the best quality from coke-furnaces, and with any species of ore: for, as I remarked at the commencement of these letters, iron being a simple element must be identically the same, let it be procured from whatever combinations it may or by any means that are possible to employ, and it must be the substance alloyed with it which gives it qualities so different from its own.

63 See Part I. p. 220, *note.*

LETTER XXV.

POTASSIUM AND IRON — SODIUM AND IRON — ELEMENTS OF THE FLUX — ITS APPLICATION IN THE REFINERY.

CHARCOAL-IRON may reasonably be supposed to contain potassium, carbon and iron; and the ready oxidation of potassium and its affinity for silex (or oxide of silicium[64]) may in some measure account for the superior quality of wrought-iron obtained from charcoal pig. If *soda* were employed in coke-furnaces, it is equally as probable that the pig from thence would contain sodium, carbon and iron, and that sodium (having, when oxidated, so powerful an attraction for silex) would displace all the silicium and leave the iron equally as pure as if it had been originally made from charcoal.

To return however to the pig from coke-furnaces: We now conclude it to be an alloy of iron, carbon and silicium; and that this last element requires to be nearly separated before the iron will recover its original welding and ductile properties. To get rid of

64 Chemists are now generally agreed in classing the base of silica among the *non-metallic* elements. In this view, the name given to it by Thomson of *silicon* would be more symmetrical than *silicium*. I have however not found it proper to alter the name used in the manuscript: which is besides still of most usual acceptation on the continent of Europe.

part of the carbon and silicium, although at the expense of a large quantity of iron, the usual method is to fuse the metal in a refinery. This fusion of the pig oxidates a large portion of the alloy (most probably in the proportions that constitute it); this assists to get rid of the carbon by the oxygen of the oxide of iron uniting with the carbon of the carburet; and a part of the silicium is no doubt oxidated and separated by the fusion of the alloy in the refinery.

As the quantity of carbon decreases, the mass thickens and would soon break into grains; but it is now tapped off into an iron-mould and forms *finer's metal.*[65] This metal has now parted with a great portion of its carbon (probably not retaining so much as steel of the lowest gradation, which has all the properties of the best iron); and yet this metal is brittle, hard and unweldable, and for the reason[66] that nearly the whole is an alloy of iron and silicium, al-

65 The *fonte mazée* of the French metallurgists.

66 I subjoin for both illustration and correction, the results of M. Berthier's analysis of the same metal before and after refining, in parts per cent.

	CRUDE-IRON.	FINERY-IRON.	
Carbon,	3.0	1.7	1.0
Silicium,	4.5	0.5	0.2
Sulphur,	0.2	0.	0.
Phosphorus,	0.2	0.	0.

The two specifications of the finery-iron are of portions from the upper and lower parts of the plate respectively. It appears from this that the principal effect of refining is to remove the *silicium;* for, taking the mean of the constituents of the finery-iron, the carbon is reduced but to 45 per cent. of what it amounted to in the crude-iron, while the silicium is brought down to less than 8 per cent. of its former amount.

though perhaps in different proportions from pig-iron. To separate this semi-metal will therefore require some other process besides mere fusion; and it will be necessary to make use of a compound affinity by employing a substance that has a more powerful attraction for silex than silicium has for iron; otherwise it is not at all probable that it will by any mechanical process, or single affinity, be ever totally separated.

I will now proceed to state the advantages that may be derived from making use of a flux made from sea-water.

Having procured this flux, (which likely may be a compound of soda, lime, silex, alumina and oxide of iron, in perhaps the following proportions, viz: lime 20, silex 14, alumina 12, oxide of iron 8, soda 46; these forming 100 parts of the flux[67]) we will next consider the most advantageous manner of making use of the same, and will conclude that the same processes will be followed as are usually employed; for to make the most trivial alterations in the manipulations is attended with so many difficulties and so much dissatisfaction that I have hitherto endeavored to keep as clear as possible from recommending any change in workmanship.

67 This may be considered as a *composite* flux, in which various elements have been superadded to the sea-salt to present the proportions given in the text. Otherwise these proportions do not at all represent the constitution of sea (or of any other) salt; except in the single particular of the soda, which is sufficiently accurate.

We will therefore commence with the flux in the finery; and to every 25 Cwt. of pig-iron melted in this fire, I would recommend 1½ Cwt. of the flux to be fused along with it.

This would cause the whole of the suspended earths or oxide in the pig to enter into fusion and consequently to separate: but the greatest advantage in using this flux will arise from the powerful affinity which exists between soda and silex and the ready oxidation of the silicium to unite with it in preference to iron.

LETTER XXVI.

BELL-METAL AND SULPHURET OF ANTIMONY DECOMPOSED — PIG-IRON BROUGHT TO NATURE AND FINISHED IN THE REFINERY — PUDDLING AN USELESS PROCESS.

THE quiescent affinity of silicium and iron, particularly when the iron is in great excess, is very considerable; and therefore to overcome this affinity it is necessary to apply some other substance whose power of attraction for silex is greater than the attraction of silicium for iron: for if this separation is attempted by single affinity only, the decomposition will never be complete, as such decompositions always leave a minimum [a minute portion] of the substance intended to be separated and very frequently some of the decomposing body itself, added to the resulting compounds; particularly in the separation of one metal from another (gold, silver and platina from the more oxidable metals excepted) or of carbon, sulphur, or phosphorus from a metal.

For instance, oxygen will decompose *bell-metal*, which is an alloy of copper and tin: the tin uniting with the oxygen becomes protoxide of tin, and the copper remaining in the metallic state, from its less

attraction for oxygen. But this oxidation of the tin can only be partial, and consequently will never separate the whole of it from the copper, for this evident reason: as the quantity of tin in the remaining compound becomes less, (from its partial oxidation) it will be then much more protected from oxidation by the remaining copper. The protoxide of tin, first formed, will readily absorb a farther dose of oxygen and become per-oxide; and this per-oxide, when in contact with the fluid metallic copper, will give up its excess of oxygen to the copper, which then becomes protoxide of copper, and the per-oxide of tin in consequence becomes a protoxide. A farther portion of tin may then oxidate from the alloy; but the copper itself will be placed in contact with more per-oxide of tin and suffer oxidation, so that the last atoms of tin will never be separated until nearly the whole of the alloy has suffered oxidation. For, in any stage of the process, the remaining metallic parts will be an alloy of copper and tin, and the oxidated portion will be a mixture of per-oxide and protoxide of tin and protoxide of copper; and therefore it is extremely probable that a single affinity will never separate metals from each other—gold, silver and platina (as before) excepted.

And as regards the separation of carbon, sulphur or phosphorus from a metal by single affinity, it will be as incomplete as the separation of a metal from metallic alloys as just stated. The separation of sul-

phur from antimony may be given as an instance of this. When crude antimony (which is a compound of antimony and sulphur) is fused and metallic iron added to it, the sulphur partly quits the antimony to unite with the iron, and the results are a mixture of iron and sulphur, antimony and iron (hence called *martial regulus*) and iron, sulphur and antimony.

There might be adduced other instances of the incomplete separation of united bodies by means of single elective affinity; in all of which, there will be a minimum of both substances in the respective products. Carbon and sulphur are, however, much more easily separated from metals, than metals are from each other, for the reason before stated. The same rule will hold good in the separation of the alloys from pig-iron; and I shall endeavor to shew, that while only a single affinity is employed to separate the alloys, the separation will always be incomplete and the result not so perfect as science is capable of producing.

The iron in passing through the refinery in contact with this [new] flux (as before stated) will be, if the operation is well performed, totally separated from the suspended earths and oxide; and also the best part of the silicium will be converted into silex and got rid of: and the result will be iron alloyed with carbon only and very much approaching the state of steel. This metal may be blown into nature in the refinery, and finished into wrought-iron without far-

ther process; and such iron would be both much better in quality and more in quantity than if it were made to undergo the operation of puddling. But this being so unusual a proceeding, it may be considered too short and too crude a process to procure bar-iron, even to be noticed for years to come; because, for one thing, it would disconcert the paraphernalia of the puddling and rolling mill, and for another, it appears too simple and straight-forward a process: so that I expect such a proposition to be in a manner twenty years before its time.

LETTER XXVII.

PUDDLING FARTHER CONSIDERED—SILICIUM SEPARATED BY DOUBLE AFFINITY.

HOWEVER as puddling is so favorite a process, I will conclude that the metal will undergo that operation and be tortured into wrought-iron (often being on the very brink of that state in the refinery) with an extra loss of 2 Cwt. or 2½ Cwt. per ton.[68]

The rationale of the puddling process, is as follows: most metals are susceptible of being broken into grains at the instant before they enter into fusion, and this is the case with finer's metal in the puddling-furnace; for, as the iron is starting into fusion, the fire is checked by means of dampers and as the metal acquires liquidity it is exposed to a considerable sur-

[68] The respective wastes in the various operations, through which the crude-iron is carried, may be taken on an average to be as follows:

Crude-iron:	2240 lbs.	give	Finery-metal:	2000 lbs.
Finery-metal:	2000	"	Puddled-bars:	1750
Puddled-bars:	1750	"	Finished-bar:	1500

Or reversing it

Finished-bar:	2240	take	Puddled-bars:	2600
Puddled-bar:	2600	"	Finery-metal:	3000
Finery-metal:	3000	"	Crude-iron:	3350

In the employment of the methods of M. Faber for using the *gases* developed during combustion, instead of solid fuel, the difference between the finery-metal and puddled-bars may be expected to be diminished.

face of air and part of it oxidates, which thickens the remainder, and the temperature at the same time decreasing causes the whole, with the assistance of the workmen, to break into a kind of sand. This part of the process is termed *drying the iron.*

The metal, in this granulated state, is of course greatly exposed to the action of the flames and of the air that may escape through the fire-place undecomposed, and also to the residuary nitrogen of the atmospheric air, and water in a state of vapor (the product of the flame of the raw fuel employed) together with carburetted, sulphuretted and phosphoretted hydrogen gases, and also carbonic, sulphurous, and phosphoric acid gases;—a pretty medley of impure substances to be brought into actual contact with iron in so divided a state as it is in a puddling-furnace. These various gases, including some fresh atmospheric air that may be casually introduced at the opening through which the tools of the workmen are applied, and also some water occasionally thrown in upon the granulated mass, are by the action of the flame reverberated upon the iron; fresh surfaces of which are continually exposed by the puddler. In this manner, part of the iron and its alloys become oxidated; the carbon is volatilized; and the remaining iron with its alloys is at last wrapped up into balls and withdrawn from the furnace, to be passed between the rolls or hammered into bars.

Such are the principles of puddling. Part of the

iron is oxidated; and this oxide of iron decomposes the remaining sub-carburet in the metal by double affinity, the carbon flying away as carbonic acid and part of the oxide of iron being again revived. The water in a state of vapor is decomposed by the iron and silicium; but this decomposition of the steam takes place upon the surface of the grains of the granulated mass only, and the nucleus of metal remains precisely in the state it was in when run from the refinery,—that is, an alloy of iron, silicium and carbon; and it will ever remain the same while the separation is continued by single affinity only, for the decomposition of water over iron and silicium cannot be considered in any other light than single affinity, viz: of iron, or silicium, for oxygen.

This process of puddling will, however, separate the carbon and sulphur pretty accurately; but it must be evident that the remaining metal is still an alloy, from the impossibility of oxidating (which is a process acting upon superficies only) the silicium in the internal part of the grains. Indeed, its brittleness, color and texture, all indicate the presence of something more than iron and carbon: and what else can reasonably be expected, except it is silicium?

Puddling is therefore a process which may be dispensed with to advantage, for what is performed by that operation may be much better done directly from the pig (without suffering the metal to cool) in the refinery; for if the silicium is not totally separated in

the refinery, it never will be afterwards, and if it is got rid of there, a very short continuance of the operation would bring the metal into wrought-iron.[69] If the whole of the carbon is not separated, I conceive it will be rather advantageous than otherwise; for the iron will never be *red-short*,—a quality which iron frequently exposed to a high temperature unprotected by carbon acquires, and there is every reason to conclude the absence of carbon in wrought-iron is indicated by the red-short quality. It appears to me therefore a delay in bringing the pig into bar-iron, to suffer it to cool after fusion in the refinery; for all that is required is to separate the semi-metals and part of the carbon, and this must be done while the mass is in fusion; and it is therefore more likely to take place in the refinery than in any after process: and provided such separation is accomplished in the refinery, and nothing but iron with a

69 Of course, this conclusion must be taken in connection with the *whole* of our author's theory upon the subject; in which view it is quite justified. *Puddling*, which is properly *refining white crude-iron in a reverberatory furnace*, grew up in the English processes, partly from the character of the ores which were earthy carbonates, not very rich,—partly from the sort of fuel exclusively used,—and partly from the demand at the blast-furnace (arising out of the extensive application of *cast*-iron) for *grey* crude-iron, i. e. iron containing a large proportion of free carbon. On the continent of Europe, except in few places where the nature of the ores or the hope of improvement have contributed to the introduction of the English method, it is unused. In America, on the other hand, where foundries have not received such extension as in England, at many establishments whose blast-furnaces furnish at once *white* crude-iron, the metal is refined at once in the puddling, assisted by a *chafery* as it is called; nearly similar to the method of Champagne.

little carbon remains, why suffer the metal to cool and consign it over to another process at the additional expense of a considerable portion of iron, fuel, time and labor?

When the metallurgical flux [before recommended] is employed in the blast-furnace, the pig will contain a much less quantity of silicium (with probably some sodium); and the re-fusion of, say 25 Cwt., of such pigs in the refinery with 1½ Cwt. of fresh flux will leave little doubt of the complete separation of the semi-metals, the mechanically suspended earths or oxide, and the greatest portion of carbon also. The remaining metal will then be in the state of steel;[70] and a short continuance of the operation in the refinery while in contact with the oxide of iron, (which will, if required, decompose all the remaining sub-carburet by double affinity,) will produce the desired weldable and ductile combinations of iron.

A small admixture of the sub-carburet dispersed through the mass perhaps causes it [still] to be in some degree brittle, but hammering or rolling will

70 I subjoin the results of M. Berthier as to the proportions of carbon and silicium (in parts per cent.) in the principal varieties of steel: *Voie Sèche* ii. 275.

	CARBON.	SILICIUM.
English Blistered-steel, per 100 parts, . . .	1.87	0.10
Indian Steel or Wootz, ...	1.50	0.60
Cast-steel made in the laboratory to imitate Wootz, .	1.65	0.10
English Cast-steel, ...	1.33	0.05

By comparing this table with the details of the note 66 (on p. 110 *ante*) it will be seen how little the subsequent processes (although they have altered the mechanical texture) may have changed the constituent elements of *finery-iron* in producing steel, and *vice versâ*.

remove such brittleness, and the result will be every thing that can in reason be desired.

I have said before that it will require a compound affinity to perfectly separate the silicium from iron, and that the simple oxidation of iron or silicium by means of water or atmospheric air is only in consequence of single affinity. The application of the metallurgical flux will overcome this difficulty, because it will operate by double affinity. Thus the soda united with the oxide of iron, having a powerful affinity for oxide of silicium or silex, predisposes this semi-metal to oxidation; and the oxide of iron having less affinity for soda than silex, the oxygen of the oxide of iron (iron also having less affinity for oxygen than silicium has under these circumstances) quits the iron and unites with the silicium, producing silex, which then immediately unites with the soda and enters into fusion along with the other elements of the flux, fuel and pig-iron; and the remaining metal will be iron alloyed with a little carbon only. This change in the elements is therefore a true double decomposition: for the compound of iron and silicium is decomposed by a compound of oxide of iron and oxide of sodium—the oxygen of the oxide of iron uniting with the silicium and converting it into silex, which then immediately enters into more firm union with the oxide of sodium and the other elements of the flux, etc. as just stated.

LETTER XXVIII.

PUDDLING UPON IRON-BOTTOMS RECOMMENDED, IF THE FLUX BE USED — FINERY-CINDERS RENDERED FIT FOR FURNACES — A PROJECT TO EQUALIZE THE WORKING OF FURNACES.

As however it is very probable that puddling will not be dispensed with for some years to come, I would recommend the using of ½ Cwt. of the flux to the ton of iron in this operation, provided this process were employed upon an iron-bottom[71] instead

71 Since this was written, the use of iron-bottoms or soles in puddling-furnaces (although for other reasons than that contemplated by our author) is becoming more universal; partly from their greater ease to the workmen and partly from a growing disposition among Iron-masters (highly favorable both to science and commerce) that the constant accessories to their various processes should be as neutral as possible, and that no agencies be introduced whose effects cannot be distinctly accounted for before-hand. I know of no objections to them, except their greater first cost and the necessity (hitherto generally existing, but by no means absolute) of taking down the inner walls of the furnace for their replacement. The methods of M. Faber, before spoken of, tend to remove both of these. It is true, the sand-bottoms (which in addition to the frequent renewals they require, the greater labor they impose, and the inconvenience mentioned on p. 98 *ante*, in speaking of puddled-bars, are admitted to cause a loss by oxidation of 2 to 4 per cent. of metal) have been adhered to by some under the supposition that the quality of the metal was improved, in consequence of an absorption of some impurities by the silica; perhaps in the same view, with which powdered glass, or siliceous matter yet more pure, was added to the crucibles in making *cast-steel*.

of one of sand:—for this reason, if the flux is employed upon sand-bottoms, it will cause it to melt and unite with the oxide of iron, soda, and the other elements of the flux, and this would be returning a large portion of the silex of the blast-furnace. But upon iron-bottoms, the flux could only operate on the silicium and earths or oxides, and the iron would be left in quite a pure state. If, therefore, iron-bottoms to the puddling-furnaces are not used, I would not recommend the application of the flux in this operation, but would prefer using the whole 2 Cwt. in the refinery.

The iron-cinders produced in the refinery by this mode of operation will then be admirably adapted for blast-furnace use; for they will contain the whole of the flux, and the iron produced from them will be as separable from silicium as if it were made immediately from the ore, a difficulty at present not readily surmounted, and therefore the finery-cinders in particular are a useless residuum at Iron-works,[72] although they contain about 50 per cent. of iron. It would be desirable and advantageous to re-fuse the puddling and mill cinders in the refinery along with the pig-iron and the flux. Such an addition would rapidly separate the carbon, and also increase the yield of metallic iron, for the reasons before stated.

[72] Except when applied, as usual on the continent of Europe, to assist in the reduction of the metal. The cinders produced in the refining are of two kinds; the soft rich cinder which arises first, and a crude, pyroxenic product

The idea of finishing iron direct from the pig may probably startle some persons who are in a manner wedded to the present processes which they have been habituated to from their infancy, and who generally cling to them with all the blind prejudice and stubborn obstinacy imaginable. It will not do—'tis impossible,—and several other such ejaculations will be expressed: but I will only put one short monosyllabic question to them—why? If they will answer me this question, without equivocation, they will themselves then demonstrate the practicability of all

which is subsequent. The former is the only species applicable to the reduction. In order to shew the peculiarities in constitution of both kinds, etc. I present in the following table the results of various analyses of M. Berthier.

	CHARCOAL.		COKE.	
	Crude.	*Rich.*	*Finery.*	*Puddling.*
Silica: . . .	21.5	11.8	27.6	36.8
Protoxide of Iron: .	67.9	80.1	61.2	61.
Protoxide of Manganese:	1.1	2.	...	...
Lime:	1.7	2.	...	...
Magnesia: . . .	trace	0.5	...	...
Alumina: . . .	0.5	1.	4.	1.5
Potassa: . . .	0.2	0.5	...	...
Phosphoric Acid: . .	6.7	1.9	7.2	...
	99.6	99.8	100.	99.3

The first column contains the mean of five analyses of crude cinder produced in refining with charcoal: the second, the mean of seven analyses of rich cinder. The third contains the elements of finery-cinder from an establishment near Dudley: the large proportion of phosphoric acid shews how the greater part of the phosphorus in the crude-iron is got rid of, in refining. The last column, containing the elements of puddling-cinder from Dowlais, I have annexed to compare the theoretical effects of that process with those of the finery, and to shew in particular the agency of sand-bottoms (spoken of in the last note) to which the large amount of silica is no doubt owing.

I have written.[73] This is a kind of logic that may dissatisfy many, and I entertain no doubt that several will condemn many other of the hypotheses herein stated. All I can say is, that if any gentleman (who subscribed to these Letters) should feel unsatisfied with the theories I have laid down, and may wish for farther explanation, I am ready and willing most respectfully to comply with his request, and will explain, either by letter or personally, and I hope satisfactorily; at all events I will endeavour to do it scientifically.

Before I conclude, I will take the liberty of inserting a project that may be adopted with considerable advantage, and at an expense that would with every probability be amply compensated in the regularity with which blast-furnaces may then be worked, and which is as follows, viz: The calcined mines, iron-cinders, kiln-dust, limestone, clay, and any other and all substances employed in blast-furnaces, (except the air and cokes) after they have been apportioned so that the remaining elements, when the iron and

[73] There is no question of the theoretical correctness of these views; nor would there have been, (had our author chosen to have gone farther,) of the affirmation that malleable iron might be made immediately *from the ore;* since this has been done from remote antiquity with the *stück-ofen* (Part I. p. 45) and is done to this day with the low-furnaces of Sweden, and in the Pyrenees after the so-called Catalan method. But the true topic for discussion is, whether such processes, especially in regard to the minerals of coal-regions, would or would not entail a disproportionate waste both of ore and combustible? M. Karsten has already considered the subject with his accustomed impartiality.

oxygen are separated, may be in the aforesaid relative proportions—I would recommend to be fused, so as to make a perfect homogeneous and chemical mixture: and when they are in complete and liquid fusion let the whole be tapped or ladled off into water; by this means the mass will be granulated and prepared for the furnaces, in a state highly favorable for future reduction; by this means, also, there will be but one material to be applied along with the cokes, and this may even be applied by *measure*, for I should conceive the doing away with weighing the mine, cinders, limestone, etc. at the trundle-head of the furnaces a very considerable advantage, since such operations are little more than nominal. In this case the charges could not easily avoid being uniform, and neither of the materials (which are now separately weighed with every barrow of coke,) could then be forgotten or what is almost as bad, thrown into the furnace at random. Such a contrivance as this would have many advantages, and therefore it is deserving of an actual experiment.

APPENDIX.

NOTE A,

(referred to on pp. 21, 49.)

The Constitution of the Atmosphere.

THAT sulphur and phosphorus may exist in the atmosphere, as stated in the text, is in some cases very likely; and generally not possible to be disproved. But that they exist, as *constituent* parts, is not recognized in the most accurate chemical researches. Their proportions when present are too minute to be detected.

Under the application of the hot-blast, by which the vapor of water in the atmosphere becomes infinitely attenuated, the component parts of the air may be considered, for all metallurgic calculations, to be as stated in Part I. p. 189, viz:

	in weight.	in volume.*
Oxygen . . .	23.	21.
Nitrogen, . .	77.	79.
	100.	100.

These proportions appear every where the same. In the

* The observations have given these proportions at 20.81 and 79.19, at the temperature of 32° F. But of course at any higher temperature, regard will be had to the specific heats of the gases respectively. Applying these in the most direct manner, the following very simple calculation gives

$$20.81 + \left(\frac{10000 \times 20.81}{9765} - 20.81\right) \times \frac{20.81}{79.19} = 20.94$$

as the mean proportionate volume of oxygen in practicable temperatures; which sufficiently justifies the statement in the text. A differentiation of the terms, assuming temperatures infinitely high, would give a still higher result.

words of Mitscherlich, "*air* has been procured and analysed from the most widely distant regions—from the vicinity of the pole and the environs of the equator—from the highest mountains as well as from valleys—from elevations attained by æronauts, and surmounting the peaks of Chimborazo, as well as from the immediate surface of the globe; and every where there has been indicated the same quantity of oxygen and the same quantity of nitrogen, except when the specimen has been plainly under the influence of particular local circumstances, as when for instance the air has been gathered from close places, from cellars or from receptacles of putrescent organic matter."

This passage has been quoted, as containing concisely a conclusion substantially admitted by all in the general; but it is not to be denied, that, in the contemplation of particulars, there have existed serious discrepancies in the results of observation even—so serious, as to have presented no means of positive decision between theoretical inferences the most opposite. So, for instance, the specific gravity of oxygen varies, according to different experimenters, from 1.1026 (the sp. gr. of dry air being 1.) of Dulong and Berzelius to 1.1117 given by Thomson.* And as a consequence of this want of definite knowledge as to the character of the individual elements, grew up a want of coincidence in opinion as to the mode of union of said elements;—the continental savans generally considering it to be but an intimate mechanical mixture, while in England especially there were high authorities convinced that it was nothing

* In illustration I append a list of the varying densities given for oxygen by different observers and nearly in chronological order.

Lavoisier,	1.1030
Davy,	1.1270
Allan and Pepys,	1.0900
Fourcroy and Vauquelin,	1.0870
Kirwan,	1.1030
Biot and Arago,	1.1036
B. de Saussure,	1.1140
Dulong and Berzelius,	1.1026
Thomson,	1.1117
Th. de Saussure,	1.1056
Dumas and Boussingault,	1.1057

less than a true chemical combination.* Again, while the uniformity of proportion of the two main elements and their constancy were firmly maintained by some and favorably regarded by most philosophers, there were most respectable persons who thought themselves justified (principally by theory but also in a measure by direct experiment) in the opinion that the constitution of our air varied with the altitude above the surface of the earth, and that the summits of the higher mountains were in an atmosphere less rich in oxygen than that which rested on the level of the ocean.

Not very long since, MM. Dumas and Boussingault have made the constitution of the atmosphere, and especially the grounds of the differences I have indicated and others, the subject of investigation;† and the mode in which they have conducted it, (apart even from their own acknowledged skill and the ample means which one might suppose would be at their disposal) furnishing so many undesigned co-incidences as appear impossible to consist with error, may be considered as decisive of the questions involved. The French Academy of Sciences has consigned the matter to a committee of its own body; with a view to the confirmation that will no doubt be afforded in consentaneous observations made at different points of the Earth's surface, under different circumstances, and with all the precautions which are every day found, in all refined observations, to be more and more necessary.

The results of the researches above mentioned have been

1°. To establish a new specific gravity for each of the elements: to wit, for

	specific gravity.
Oxygen . . .	1.1057
Nitrogen . . .	0.9720

2°. To harmonize the elementary proportions of the atmosphere with the numerical relations of a simple alligation of fluids; and thus to furnish, what has not been done before, the

* See for instance a communication of Dr. Thomson in the *Comptes Rendus:* xii. 1048 *ss.* It is to be remarked that the eudiometrical measures of this chemist were made upon no larger quantity than one cubic inch of air; the $\frac{1}{100}$ of which represented a volume.

† *Comptes Rendus:* xii. 1009 *ss.*

means for an arithmetical proof of the absence of chemical action. As this was to me of great interest, I may be allowed to dwell longer upon it and even to presume upon an extension of the demonstration.

All chemical action is, as far as we know, accompanied by a developement of heat; and, as a consequence of this heat, arises generally a change of volume in the body or bodies heated. The change may be either an expansion or contraction, according to circumstances of constitution over which the accidents of contiguity and chemical affinity have no control; and it may even happen in excessive cases that the alteration of texture (if I may use such a phrase) will render the heat actually developed insensible, or more. So it is in the case of frigorific mixtures.

Which ever way the change of volume may occur, there is of course at the same time an inversely corresponding change of density; so that in the case of two fluids, for instance, chemically combined, the density of the resulting compound is no longer the proportional aggregate of the densities of its elements.

In cases of mere mechanical mixture, on the other hand, there is neither developement of heat, change of volume, nor loss of correspondence between the individual and aggregate densities and volumes: so that wherever substances are observed to unite under all these circumstances, they may be taken as mechanically, not chemically, combined.

I have been particular to say under *all* these circumstances; for there are cases of true chemical combination, presenting otherwise the relations of accurate alligation. Such, for instance, is the binoxide of nitrogen or nitric oxide (an example closely allied to the subject in hand) consisting of equal volumes of oxygen and nitrogen combined without any change of volume. Such, too, are the compounds of hydrogen with chlorine, iodine and bromine; whose respective volumes and densities are correlative. But all of these present physical proof of chemical combination, during their production.

The necessary correspondence, then, required to affirm mechanical mixture has been shewn by MM. Dumas and Bous-

singault, thus: They found, by a number of experiments, in a given weight of air, called 1.

the weight of the oxygen = 0.2301
the weight of the nitrogen = 0.7699

Combining these with the specific gravities before given, the sum of both divided by their densities respectively should represent (if they are accurate proportionals) the unity of that volume of air, whose density was called 1.; or in fact

$$\frac{0.2301}{1.1057} + \frac{0.7699}{0.9720} = 1.$$

This equation, a very short arithmetical operation shews to hold good. The resulting elementary volumes, viz:

$$\frac{0.2301}{1.1057} = 0.2081 \text{ oxygen in volume}$$

$$\frac{0.7699}{0.9720} = 0.7919 \text{ nitrogen in volume}$$

agree sufficiently exactly with the conclusions from independent experiments to warrant the belief that there can be no error of any importance now involved in the subject.

These considerations may be extended so as to show

First: that, admitting the new specific gravities to be accurate, the proportions of oxygen and nitrogen can only be represented (unless there is a change of volume) by numbers identical, or nearly so, with those which have been found by experiment.

Let, for instance, the respective volumes of air, nitrogen and oxygen be represented by V, v, and v'; and the respective densities be taken as 1, $1-a$, and $1+b$.

Then, as there is no change of volume,

$$V = v + v'$$

and for convenience calling the volume of air resulting from the mixture, unity:

$$v + v' = 1$$

so as that $v = 1 - v'$; and conversely, $v' = 1 - v$: then, as what is true of the whole must be true of its parts, the sum of the constituent volumes, each multiplied by its own density

must equal the product of the resulting volume by its density: i. e. $V = \overline{1-a}.v + \overline{1+b}.v'$

Eliminating successively v' and v, we find

$$v = \frac{b}{a+b} \text{ and } v' = \frac{a}{a+b}$$

for the expression of the respective volumes in terms of the densities.

Now substituting for a and b, their values 0.028 and 0.1057 respectively, we have

$$\text{for the volume of nitrogen: } v = \frac{0.1057}{0.1337} = 0.79058,$$

$$\text{volume of oxygen: } v' = \frac{0.0280}{0.1337} = 0.20942,$$

volumes almost identical with those of M. Dumas.

Nor will this hold less good if applied to the elementary proportions in *weight*.

Retaining the same notation, if we farther call P, the weight of a given quantity of air, which is made up of the separate weights, p, and p', of nitrogen and oxygen respectively; in such wise that P, p, and p' shall correspond to V, v, and v': then, the weights being as the volumes and densities combined, we shall have

$$p = v.\overline{1-a} \text{ and } p' = v'.\overline{1+b};$$

substituting for v' and v, their values before obtained in terms of the densities and we find

$$p = \frac{b-ab}{a+b}, \text{ and } p' = \frac{a+ab}{a+b},$$

for the expression of the respective weights in terms of the densities. Now if for a and b, we use their numerical values before given we shall obtain

$$\text{for the weight of nitrogen: } p = \frac{0.1027404}{0.1337} = 0.76844$$

$$\text{weight of oxygen: } p' = \frac{0.0309596}{0.1337} = 0.23156$$

weights which do not materially differ from those obtained by experiment.

If the specific gravities are right, therefore, the ascertained weights and volumes are accurate likewise. It is manifest that if we assign to P an absolute value other than unity, a converse operation would prove the converse proposition.

Secondly: admitting the experiments as to density and proportionate weight or volume of *either of the elements* to have been accurate, the density, weight and volume of the other element cannot be represented but by numbers identical, or nearly so, with those already independently obtained; or, in other words, that a calculation *a priori* accords with experiment *a posteriori*.

I shall not carry the numerical examples out in full for each; but shall content myself with taking the results for *oxygen*, and those in so far as they relate to *weight* only, the experimental observations for which are capable of being conducted more unexceptionably than eudiometric measurements of volumes.

MM. Dumas and Boussingault find the density of oxygen to be 1.1057 (whence agreeably to the notation hitherto employed, $b = 0.1057$) and its mean proportionate weight (p') 0.2301.

Substituting these values, then, in the equation

$$p' = \frac{a + ab}{a + b},$$ we derive a = 0.0278 and thence

the specific gravity of nitrogen = 0.9722
The experiments gave = 0.9720.

Applying the value of a in the other equation

$$p = \frac{b - ab}{a + b},$$ we obtain p = 0.76975

instead of . . . . . 0.76990 as found by the experiment.

These verifications, which might be extended throughout, are sufficient to shew the reliability of the results obtained. They indicate also, what is quite conformable with these results, the propriety of taking for

	specific gravity.
Specific gravity of oxygen . .	1.1058
nitrogen . .	0.9722

These applied in the equations last employed would give values

of p and p', differing only in the seventh place of decimals from those furnished by observation.

Thirdly: in no point will the proportions required by the theory of chemical composition accord with the observations given above.

Chemically, the respective volumes of nitrogen and oxygen would be required to be as 4 to 1; now recurring to the equations

$$v = \frac{b}{a+b} \text{ and } v' = \frac{a}{a+b}$$

and expressing them in proportions, thus

$$a+b : b :: 1 : v$$

and $$a+b : a :: 1 : v'$$

we have, *ex æquali*,

$$b : a :: v : v'$$

But in the chemical theory

$$v : v' :: 4 : 1$$

that is $$b : a :: 4 : 1$$

Therefore if the sp. gr. of oxygen be taken as accurate, the sp. gr. of nitrogen, instead of 0.9722, would have to be 0.9736: or, if the nitrogen be taken as the basis, the oxygen instead of 1.1058 would have to be 1.112. It is impossible to admit that observations made at the present day, by men less skilful than the distinguished experimentalists, should be so much *en écart*.

The chemical theory is still less supported by the proportionate weights. If we deal with the equations affecting p and p' as we have just now done for v and v': we may state

$$a+b : b-ab :: 1 : p$$

and $$a+b : a+ab :: 1 : p'$$

Hence $$b-ab : a+ab :: p : p'$$

Now the atomic relations require that the oxygen and nitrogen should be in the proportion of 8 to 28;

i. e. $$p : p' :: 28 : 8$$ and

$$b-ab : a+ab :: 28 : 8$$

Calculating then this proportion from the sp. gr. of nitrogen (0.9722) which is admitted by all to be very near the truth, we

derive a specific gravity for oxygen of 1.1276: a result not to be supposed possible, without discrediting the best experiments.

3°. To guarantee the strong conviction, if not absolute certainty, that the constitution of the atmosphere is constant at all epochs and places.

On the first point, the re-weighing of a litre of air in 1839 by MM. Dumas and Stas (which they find 1.2995, while Biot and Arago had made it 1.2991) and the agreement of their present results with the analysis of Humboldt and Guy Lussac in 1803—serve to shew, that no appreciable change has occurred in nearly forty years. Also, the difference in proportion of oxygen, in air analysed during a prevalence of clear dry weather, and that employed during rainy weather (viz. 23.01 in the first case and 23.015 in the second) seems to belong to this category.

On the second point, their present researches at Paris, those of M. Boussingault in the Andes, those of M. Brunner at Berne and on the Faulhorn (among the Bernese Alps) during an entire month (July, 1839), and those of M. Verver at Groningen, are quoted to shew an absolute coincidence of composition.

Such are the particulars which, though not relating emphatically to the manufacture of iron, I have thought it interesting to give touching the two main elements in the atmosphere.

As to the third element, the carbonic acid, Mitscherlich gives as the result of atmospheric analyses near Geneva, for the proportion of carbonic acid: maximum 0.000574 in volume
minimum 0.000315 do.
mean . . 0.000445 in vol.

Saussure's quantities are not materially different:
viz: maximum 0.000620
minimum 0.000370
mean . . 0.000495 do.

The common mean of these is 0.00047 in volume, corresponding to (0.00047 × 1.52 =) 0.00071 nearly in weight; or about $\frac{1}{1500}$ and $\frac{1}{1000}$, in round numbers of each relation respectively. Therefore, in every 1000 cubic feet of air (weighing 76.5 lbs. avoirdupois) which is supplied to a fur-

nace, there will be furnished in the same time, on an average, 0.47 cubic feet of carbonic acid, weighing 0.055 lbs.*

And if we take the case of a charcoal-furnace, blown into at the rate of 900 cubic feet per minute, while the whole quantity of air in a turn of 12 hours will be 648,000 cubic feet weighing 50,000 lbs. nearly, the entire amount of carbonic acid in the same period will be little more than 300 cubic feet or 35 lbs. in weight.

The remaining ingredient, aqueous vapor, is more variable according to localities and according to circumstances in the same locality. It also causes, when *hot-blast* is not employed, a notable difference in the working of furnaces. This can be practically remarked in the results of the same establishment, for instance, according to the different seasons of the year.

* The new specific gravity of oxygen, already indicated, renders necessary a corresponding alteration in the specific gravity of carbonic acid; which is derived from the following considerations. The researches of M. Dumas have terminated in shewing the definitive combination-number of carbon to be 6.; while that of oxygen is admitted universally to be 8.: which numbers would shew the relative specific gravities of the two elements, if combining in equal volumes. But the combination-mode of oxygen being in demi-volumes, it follows that its sp. gr. will be to that of the vapor of carbon as 16 to 6, or as 1 to 0.375. The sp. gr. of oxygen then being taken at 1.1058, that of carbon-vapor will be ($1.1058 \times 0.375 =$) 0.414675.

One volume (or two demi-volumes) then of oxygen	of sp. gr.	1.1058
with one volume of carbon-vapor . . .	of sp. gr.	0.4147
form one volume of carbonic acid . . .	of sp. gr.	1.5205

which is what I have employed substantially in the text. Farther, this number is fully within the limits of experimental densities, as will be seen in the following list:

	specific gravity.
Carbonic acid, by Allan and Pepys, . . .	1.5240
B. de Saussure, ...	1.5180
Biot and Arago, ...	1.5196
Berzelius and Dulong, . .	1.5245
Thomson, (inferred) . .	1.5277
Turner, do. . . .	1.5239

In a special chemical treatise, it would be of interest to present the investigation of the alligations of this element in the atmosphere, and to shew the modifications therefrom of the sp. gravities of the two other elements: here it would be out of place.

The tables that have been constructed upon theory and experiment of the pressure of the vapor of water under different temperatures, taken in suitable connection with observations of the dew-point and of the barometer, enable us readily to determine the proportion of vapor existing in the atmosphere at the period of such observations. Thus, at Baltimore, in the year 1836, the monthly means of the barometer, hygrometer and proportion of vapor, were as follows:*

1836.	Barom.	Ther.	Dew-Point.	Vapor in volume.	Vapor in lbs. for 1000 c.ft. of Blast.
January,	29.95	31.°	18.°48	0.00444	0.21
February,	30.01	26.	9.58	0.00323	0.15
March,	30.03	36.5	15.35	0.00403	0.19
April,	30.04	51.5	34.	0.00772	0.36
May,	29.94	64.5	49.45	0.01312	0.61
June,	29.90	68.	60.	0.01873	0.87
July,	29.90	76.	64.	0.02127	0.99
August,	29.97	71.	58.25	0.01769	0.82
September,	30.00	69.	56.73	0.01680	0.78
October,	29.93	46.5	32.	0.00722	0.33
November,	29.97	39.5	25.20	0.00504	0.23
December,	30.09	31.	16.	0.00409	0.19
Mean,		50.9	36.59	0.01028	0.48

The 1000 cubic feet is rather more than the Maryland charcoal-furnaces receive per minute: but we shall not be far

* Trans. Maryland Academy of Science, vol. i. p. 175 *ss*.

In calculating the last column of the table, as great accuracy and refinement were not called for, I have employed a very simple formula that may be advantageously used in similar cases. Calling the barometric pressure b, the means of the thermometric and dew-point columns respectively t and d, the elastic force of vapor at its constituent temperature V, the specific gravity of vapor 0.625, that of air under the same pressure and temperature being 1, and 0.0765 lbs. the absolute weight of a cubic foot of atmospheric air at the mean pressure and temperature; then

$$\frac{V}{b} \cdot \frac{0.625}{1+\frac{(t-d)}{480}} \cdot 76.5 = w$$

w, being the absolute weight of vapor in 1,000 cubic feet of air.

wrong in allowing for them, as a general average, a half pound of aqueous vapor as entering the furnace every minute. In summer, this proportion is raised to nearly a pound; in winter, it falls to the one-sixth of a pound per minute.

To parallel the case of this ingredient with that of the carbonic acid, it may be added that in the instance of a furnace taking 900 cubic feet of air per minute, the average quantity of vapor taken in along with it, during one turn of 12 hours, will be nearly 6666 cubic feet (46660 gallons) weighing 311 pounds.

As for other substances, like those with whose mention we begun this article, they may exist either accidentally or permanently: but in either case, I apprehend, in chemical combination among themselves. They are generally volatile oils arising from natural or artificial sources, and those compounds of carbon and hydrogen and azote, derived from vegetable or animal decompositions. How far, as some have believed, they include particles ever passing off from all substances by an insensible evaporation, and thus furnishing elements to be converted in due time into ærolites, I shall not now stop to discuss. Though they have much interest in other relations of the atmosphere, (as, for instance, in regard to hygiene,) they need not be taken in account of metallurgic operations: and although they are capable of being decomposed and are therefore ponderable, their circumstances are such that it is not possible to form as yet any estimate of their quantity.

NOTE B,

(referred to on pp. 21, 87.)

On the Proportions of Materials.

THE proportions given in the text of p. 21, however they may have answered either the special locality or the epoch of our author, are inaccurate now; as will appear by the following particulars.

I. *The Coke-furnaces* of Great Britain may be assumed as producing on an average, each 10 tons of iron in 24 hours; i. e. 70 tons per week. Hence, we may easily make the calculation of the corresponding consumption of materials: viz.

1. Ore: The average quantity required for producing 1 ton of crude-iron is 3.015 tons, i. e. 6753.6 lbs. or (at 213 lbs. per cubic foot) 31.7 cubic feet of ore. This, combined with the daily yield and expressed in terms which are habitually used in speaking of the blast, is equivalent to a consumption per minute of
   0.22 cubic feet weighing 46.9 lbs.
2. Coke: The average quantity required in producing 1 ton of crude-iron is 2.8 tons, i. e. 6272 lbs. or (at 56¼ lbs. per cubic foot) 111.5 cubic feet of coke. This, combined as just now, is equivalent to a consumption per minute of
   0.77 cubic feet weighing 43.56 lbs.
3. Alkaline Flux: The average, with 1 ton of crude-iron produced, is 0.75 ton, i. e. 1680 lbs. or (at 168 lbs. per cubic foot) 10 cubic feet of limestone. This is equivalent, as before, to a consumption per minute of
   0.07 cubic feet weighing 11.66 lbs.
4. Air: We should attribute to a furnace of the assumed capacity, the consumption of 3000 cubic feet of air per minute; which will weigh, under the average pressure of 2.5 lbs. per square inch, 269 lbs. avoirdupois.

The assemblage of the details may be presented as under:

Materials consumed in Coke-furnaces.

PER MINUTE.	SOLIDS.			TOTAL SOLIDS.	TOTAL GASEOUS.
	ORE.	COKE.	FLUX.		
Volume in cubic feet,	0.22	0.77	0.07	1.06	3000.
Weight in pounds avdp.	46.90	43.56	11.66	102.12	269.

The *solid* materials then, in coke-furnaces, make up only the $\frac{1}{3000}$ in volume, or $\frac{1}{10}$ in weight, of the whole charge; and for every pound of inelastic material is supplied rather more than $2\frac{1}{2}$ pounds of the elastic.

II. *The Charcoal-furnaces* of Maryland may be rated, on the average, at 30 tons of crude-iron, each, per week. With this, we may go on to calculate the corresponding consumption, viz:

1. Ore: The materials used in these furnaces being *brown hematites* and *altered* carbonates of iron, the former yielding more than 50 per cent. of metal, there is required for producing 1 ton of crude-iron only 2.45 tons, i. e. 5488 lbs. or (at 245 lbs. per cubic foot) 22.4 cubic feet of ore. This, combined with the average rate of product, shews a consumption per minute of

   0.067 cubic feet weighing 16.33 lbs.

2. Charcoal: It is difficult to be precise in this item; inasmuch as it is charged sometimes by measure, sometimes by weight. But as far as the observations go, there appears to be required for 1 ton of crude-iron, 2280.5 lbs. or (at $31\frac{1}{4}$ lbs. per cubic foot) 73 cubic feet of charcoal. This, at the before given rate of product, corresponds to a consumption per minute of

   0.217 cubic feet weighing 6.78 lbs.

3. Alkaline Flux: For this, the greater part of the establishments referred to (all, in the tidal districts of Maryland) use *oyster-shells*, as being the most conveniently accessible calcareous matter. The average quantity used is, per ton of crude-iron made, 575 lbs. or (at 160 lbs. per

cubic foot) 3.6 cubic feet of the substance of the shell. This rated on the weekly product shews a consumption per minute of

nearly 0.011 cubic feet weighing 1.71 lbs.

4. Air: We allow to these furnaces 900 cubic feet of air per minute; which, at the mean pressure of $1\frac{1}{4}$ lb. per square inch, will weigh very nearly 75 lbs. avoirdupois.

So that, assemblage may be made as follows:

Materials consumed in Charcoal-furnaces.

PER MINUTE.	SOLIDS.			TOTAL SOLIDS.	TOTAL GASEOUS.
	ORE.	CHARCOAL	FLUX.		
Volume in cubic feet,	0.067	0.217	0.011	0.295	900.
Weight in pounds avdp.	16.33	6.78	1.71	24.82	75.

Hence it appears, that in charcoal-furnaces the general proportions of materials do not vary substantially from those of coke-furnaces; although in the details, there are marked differences. Thus in both, the solid materials, estimated by *volume*, are the $\frac{1}{3000}$ of the charge; and by *weight*, while in coke-furnaces they form 30 per cent., in charcoal-furnaces they are 33 per cent. of the charge. But if, for instance, we take the charge of *ore* as the standard or unity, we see that by *weight*, the proportions are in

	Ore.	Fuel.	Flux.	Air.
Coke-furnaces, .	1.	0.93	0.25	5.75
Charcoal-furnaces,	1.	0.42	0.10	4.60

This correction is applicable to the statements made on p. 88.

A similar comparison by *volume* would be less satisfactory both because of the differences between the volume derived from the specific gravity of the substances respectively and the habitual commercial unit of each, and because of the discrepancies of these commercial units themselves. Thus, for instance, a regular cubic mass of charcoal, measuring one foot in each of its three dimensions, will weigh 31 lbs.; but a bushel of charcoal, occupying one-fourth more space, weighs only 16 lbs. Again, the observed weight of a bushel of char-

coal is very nearly 40 per cent. of its theoretical weight; while with oyster-shells, the observation is but 28 per cent. of the hypothetical deduction.

In the preceding calculations, I have used the *relative* specific gravities of the different materials to ascertain their volumes; which are, then, as if the several substances were in a single compact mass respectively. This assumption is obviously permissible upon the hypothesis of a momentaneous consumption and supply; and it holds the mean of the ratios which would have been established: 1°. by using the ordinary commercial units of volume, and 2°. by employing the *absolute* specific gravity as a term of comparison.

Finally: coke and charcoal furnaces may be directly compared by *weight* of ingredients consumed in any given time in each—the weights for the charcoal-furnaces being throughout called unity:

	Ore.	Fuel.	Flux.	Air.
Charcoal-furnaces, .	1.	1.	1.	1.
Coke-furnaces, .	2.9	6.4	6.8	3.6

These ratios hold good on the assumption that the quantities operated upon at once, i. e. *the capacities of the furnaces*, are in the relations of 3 to 7 respectively. If the capacities, in both instances, be assumed the same (as is supposed in the deductions on p. 88) the corresponding ratios will be derived, by dividing those here given by the fraction $\frac{3}{7}$; the resulting ratio in the consumption of *air* will be, then, the exponent of the fusibility of the materials, respectively.

NOTE C,

(referred to on p. 22.)

On the Fusing point of Iron.

My principal inducement to make a note here was in seeing that, notwithstanding forty years ago the inaccuracy of Wedgewood's pyrometer (by whose indications the fusion of iron had been measured) were vividly pointed out, and thirty years ago Guyton-Morveau had shewn that the degrees of Wedgewood's scale were overrated more than one hundred per cent. by its inventor, still results from such an instrument continued to be frequently quoted and tabulated. Thus we may see in several recent publications, elementary, *e professo*, and of the hand-book order, the melting point of iron recorded as nearly 18,000° of Fahrenheit's thermometer; an enormous temperature wholly inconsistent, (if impressed on large masses, as we see done every day) with the animal organization, even, of the workmen employed in producing it.

The calculations which I have previously given, (Part I. p. 248) of the heat which can be sensible in a furnace, are sufficient, in their approximations, to shew that this temperature is extravagant. But I propose in this note to offer some farther considerations, which may serve to fix more precisely our ideas on the subject.

To those who have acquainted themselves with the steps of physical learning in the last three-quarters of a century, this very matter presents a remarkable instance of the (I will not say, revolutions of opinion, but) oppositeness of current statements which, like tides, affect the march of the sciences of observation. It would be beyond my purpose to make here an historical notice of all that has taken place upon this question; but I will quote, in illustration of my remark, a few prominent circumstances.

For instance, from experiments ingeniously contrived and well-founded in principle, if only met by commensurate mechanical accuracy (a tube of iron with one very small orifice, introduced into a furnace, was heated, as far as could be without fusion; the orifice was then stopped with a piece of wire, and the apparatus withdrawn and plunged under water; after it had acquired the temperature of the atmosphere, the wire was withdrawn under the water and the expansion of the inclosed air measured by the volume of water which then entered the tube) Lambert calculated the fusion of iron to occur at 1978° Fahr., equal to 1081° Centigrade, nearly.*

When some time afterwards the 130th degree of Wedgewood's pyrometer was reached with melting iron, the conclusion was, agreeably to the scale which had been announced for that instrument, that the temperature required for fusion was 17978° F., or 9970° C.†

A little after the beginning of this century, Guyton-Morveau, who was aware of the result of Lambert and cites it as (*au-dessous de toute vraisemblance*) below all likelihood, concluded from experiments carefully made under his own direction by Clement and Desormes, the point of fusion to be at 6346° Cent. equal to 11455° Fahr.‡

It is true, that this estimate was derived from indications of a Wedgewood pyrometer (to the rectification and developement of which, M. Guyton had applied a portion of his extraordinary activity, patience and skill) and professes to be upon *corrected* readings of its scale. If these corrections, however, had been applied only to the *scale*, and Wedgewood's own readings had been taken for the matter to be corrected, the result would have been 5095° C., or 9202° F., retaining Wedgewood's zero; and only 4783° C., or 8642° F., with Guyton's new zero.

Other results were obtained by the same Desormes and Clement, in experiments with a calorimeter; and they state the point of fusion to be 3902° F., or 3988° F., according as the direct or inverse mode of using the calorimeter (i. e. the heat-

* *Annales de Chimie*, lxxiv. 45. † *Phil. Trans.* lxxii. 319.
‡ *Annales de Chimie*, lxxxvi. 27.

ing of water or the liquefaction of ice) be adopted.* These numbers correspond, on the Centigrade scale, with 2150° and 2198° respectively.

Finally, Mr. Daniell has observed, with an extension-pyrometer of his own construction, elaborately compared with the best experiments on expansion, the fusion of cast-iron to occur at 2786° F. corresponding with 1530° C. When ultimately corrected, he rates it still lower.†

So, we see the estimation of this fusing-point, beginning at about 1000° C., rise to 10,000° C. and recently return to about 1500° C.; with the probability that it is rather below than above this last mentioned point.

All these results, to which I have referred, have been obtained from experiments more or less directly made upon the point at issue. I do not intend to discuss the bearing of the several steps taken in each, nor analyse their respective merits or trustworthiness; although hereafter some interest might attach to such an investigation. I shall confine myself to an inquiry how far other experiments, not made with a view to this special point, are capable of being converted into indirect testimony upon it.

In investigating this subject analogically, (I do not say, *analytically*, for that would imply a higher state of knowledge in regard to the various forces, active and acting, than I suppose we possess as yet) the simplest aspect of the phenomenon of *fusion* is that of a *destruction of cohesion*. In this aspect, we replace the very difficult pyrometric observation, by the easier experiment of extensibility with straining forces.

It is much to be regretted, that so far we are deficient in accounts of well-conducted experiments to this end: and of all that have been made, it may be said, that either the arrangements for registering the actual extension were not refined enough, or the results of such registry are involved in the function of respective (not absolute) cohesion, and so come to

* I give these numbers upon the authority of Mr. Daniell.—*Phil. Trans.* 1830, p. 261.

† *Phil Trans.* 1831, p. 452.

partake of the approximate character of the formulæ for expressing such functions, or the limit has not been defined between the total destruction of cohesion (or its lower grade loss of elastic force) produced by a certain weight or force of any kind acting for a long time, and what is produced by a much greater weight or force operating in a shorter time. The elaborate experiments of Mr. Telford,* which to be sure had another aim, are illustrations of the first and third of these categories; those of Tredgold and Rennie, of the second. The insular philosophers have not been more unsuccessful than the continental ones; as will be seen in the following statements, containing the latest and best observations which have come under my notice, of the extension nearest preceding rupture. These experiments are all on the *absolute* tenacity of malleable-iron; and the ultimate extension is expressed in parts of the original length, which is taken as unity.

	No. of observations.	Extension. maximum.	minimum.	Mean.
Seguin, . . .	5.	0.054	0.025	0.015
Telford, . . .	4.	0.154	0.104	0.124
Minard and Desormes,	22.	0.185	0.025	0.086
Brown, . . .	7.	0.123	0.005	0.060
Emile-Martin, .	48.	0.243	0.070	0.196

The other experimenters on absolute tenacity (in number about twice as many as those here given) either have not registered the extension at all (as Brunel and Rondelet), or have confined themselves (as Barlow and Duleau) within the limits of an elasticity yet perfect. These last are therefore inapplicable to our present purpose.

It will be seen, that I have restricted myself to the observations on *malleable* iron; because it seems much more likely that a coincidence of result might be obtained for a substance of comparatively uniform constitution and texture, than that experiments on crude-iron, which varies almost for every locality, should be in accord. But the table shews that not even in this more favorable case, is there an agreement suffi-

* Barlow: *Strength of Materials*, etc. p. 269. Lond. 1837.

cient to warrant any reliance on an indiscriminate mean; nor in the wide margin, which exists between the maximum (0.243) of Emile-Martin and the minimum (0.005) of Captain Brown, are we able to locate with any preciseness the necessary constants for a calculation, which, to have any practical value, must deal with quantities either exact or infinitely approximative.

Mr. Tredgold* has, it is true, combined the observations of respective cohesion with an elevation of temperature, in such a manner as to deduce the variation of cohesive force: but apart from the apparent want of precision in the experiment (other than that guaranteed by the singular sagacity of the observer) it was confined to a range not exceeding 150° Fahr.; and there is otherwise reason for concluding that the law of deflection is materially changed, after the limit of elasticity has been passed and the position (in space) of the neutral axis changed. However, his conclusion was that iron loses the $\frac{1}{3000}$ of its cohesive force by an elevation of temperature corresponding to 1° Fahr. This would place the epoch of total destruction of cohesion, i. e. *fluidity*, at (approximately) 3040° Fahr. or 1671° Cent.

In the absence, then, of sufficient data for calculation upon this simple hypothesis, we are left to the resource of deducing the law of expansion by heat from existing observations at easily practicable temperatures, and in applying it to more elevated ones, of finding its limit by comparison with other recognized physical laws governing the constitution of the metal. Such deduction, and the attempt to establish the limitation, (which must exist, whether we are able to define it or not) will occupy the principal part of the remainder of this note.

The observations open for resort have been, chiefly, of the expansion in one direction, i. e. of extension in length. But, as the law must be the same for any one direction and for the aggregates, and so the only question be of the exactness of quantities, (not ratios,) it appears to me that we are warranted in using the observations of either kind that may be most con-

* *Essay on Cast Iron:* p. 104. Lond. 1824.

venient, and even (if it should be necessary) of interchanging them reciprocally. In such reciprocation it is proper, however, to have regard to the exact geometric relations; and thus to escape the inaccuracies arising from the neglect of differences of the third order for instance, which, although inappreciable at first, become, in a rapidly divergent series, of consequence at high temperatures. At least, such is the way which I have prescribed to myself. For example, in employing the expansions recorded by Dulong and Petit (I may remark, once for all, that when I use the word *expansion*, I mean an expansion in *volume*, as contrasted with an *extension* in *length* or any lineal dimension) if we neglect the two last terms in the equation giving the correlations of the two quantities, viz:

$$1 + E = 1 + 3t + 3t^2 + t^3$$

we should have an extension at 100° C. of . 0.00118203
instead of more exactly 00118060;
and an extension at 300° C. of . 0.00440529
instead of 00438579

In ascending to temperatures such as those which appear, from the former part of this note, to occur at the fusion of iron, the differences of a converse operation would be in the second or third decimal place.

The results of experiments on the extension of iron in different states, recorded or deduced, are sufficiently numerous; as will appear by the following table, which I present not for curiosity or general interest merely, but specially to shew that up to the temperature at which water becomes vapor, the extensibility of iron is pretty well ascertained,* and that the error of a general mean is in very different circumstances from those indicated for the table of extensibility by weight, which I just now had occasion to give.

* Of course, I do not intend to include in this remark some of the earlier observations, and such as in the table are thus (?) noted. The reason for their insertion in a statement, professing to be nearly complete, is obvious.

Table shewing the Extension of different varieties of Iron; heated from 0° to 100° C. i. e. from 32° to 212° F. original Length being Unity.

VARIETIES.	PROPORTIONATE EXTENSION.	BY WHOM DETERMINED.	REMARKS.
Cast-iron, second fusion,	0.0010717914	Daniell,	Phil. Tr. 1831. p. 443. *inferred* from 1. at 62° F.
Cast-iron, do.	0 001109383½	Roy,	Phil. Tr. lxxv. 490. Prism 5 ft. long.
Cast-iron, ?	0.0011111	Lavoisier,	Young: Nat. Phil. ii. 390.
Iron,	0.000600?	Bouguer,	Ann. de Ch. lxxiii. 263.
Iron,	0.000730?	Muschenbroek,	ib.
Iron,	0.000920	Juan,	ib.
Iron,	0.001070	Herbert,	ib.
Iron,	0.001146	Ellicott,	ib.
Iron,	0.001166	Borda,	ib.
Iron,	0.0011806	Dulong & Petit,	Ann. de C. & P. vii. 141.
Iron,	0.0012534363	Hassler,	Am. Phil. Tr. N. S. i. 226. Bars 26 ft. long.
Iron,	0.001253333½	Smeaton,	Phil. Tr. xlviii. 612.
Iron,	0.00133901	Berthoud,	Ann. de Ch. *ubi supra.*
Wrought Iron,	0.0011810324	Daniell,	Phil. Tr. 1831. p. 443. *inferred.*
Soft forged Iron,	0.00122045	Lavoisier & Laplace,	Biot: Physique, i. 158.
Annealed Iron,	0.00133	Muschenbroek,	Young: *u. s.*
Hammered Iron,	0.00139	do.	ib.
Iron rod,	0.001446	Hallstrom,	Lardner: Treat. on Heat, p. 404.
Round Iron, wire drawn,	0.00123504	Lavoisier and Laplace,	Biot: *u. s.*
Iron wire, hard drawn,	0.00144000	Troughton,	Ed. Encyc. Art. *Expansion; inferred* from 60° F.
Steel,	0.000770?	Muschenbroek,	Ann. de Ch. *ubi supra.*
Steel,	0 001070	Ellicott,	ib.
Steel,	0.0011574	Lavoisier,	Young: *u. s.*
Steel,	0.001160	Deluc,	Ann. de Ch. *u. s.*
Steel,	0.0011898	Troughton,	Young: *u. s. inferred* from expansion for 1°.
Steel,	0.001270	Juan,	Ann. de Ch. *u. s.*
Steel rod,	0.001144733½	Roy,	Phil. Tr. lxxv. 480. 5 ft. in length.
Annealed Steel,	0.00122	Muschenbroek,	Young: *u. s.*
Annealed Steel,	0 00123189	Berthoud,	Ann. de Ch. *u. s.*
Blistered Steel,	0.0011238	Mudge & Dalby,	Phil. Trans. lxxxv. 428. Steel chain.
Blistered Steel,	0.001150	Smeaton,	Ph. Tr. xlviii. 598.
Hard Steel,	0.001225	Smeaton,	Phil. Tr. xlviii. 612.
Tempered Steel,	0.00127	Muschenbroek,	Young: *u. s.*
Tempered Steel,	0.00137472	Berthoud,	Ann. de Ch. *u. s.*
Untempered Steel,	0.001079155	Lavoisier & Laplace,	Biot: Physique, i. 158, mean of two observations.
Steel tempered yellow,	0 0013775	do.	ib. do.; *inferred* from expansion to 30° C.
Steel tempered yellow,	0.00123956	do.	ib. *inferred* from expansion to 65° C.

One of the observers named in the foregoing table, Hallström, measured the extensions for every ten degrees of the Centigrade thermometer. His results, which are of great interest for the present purpose, I embody below.

Extension of Iron at various temperatures, from 0° to 100° C. length at 0° being unity.

Temp.	ϵ	diff.	Temp.	ϵ	diff.
10°	0.000102	102	60°	0.000734	146
20°	.000211	109	70°	.000892	158
30°	.000328	117	80°	.001063	171
40°	.000453	125	90°	.001247	184
50°	.000588	135	100°	.001446	199

One need only look at this table to be struck with the regularity of the column of differences; which for greater illustration, I have interpolated. In fact, by carrying the differences out until they become constant (as they do in the third place) it is easy to see, that the quantities of extension are expressed by an equation of the form

$$\epsilon = ax + by + cz$$

x, y, and z, being constants given by experiment; and the co-efficients, a, b, and c, being numbers dependant on the ratio of the series. This series containing no quantities higher than the third power, the co-efficients are convertible, (if we take n to represent the term in the arithmetical progression of temperatures, so that $n = \frac{t°}{10}$) as follows, viz:

$$a = n \quad . \quad . \quad . \quad b = n.\frac{n-1}{2} \quad . \quad . \quad . \quad c = n.\frac{n-1}{2}.\frac{n-2}{3}$$

and the equation becomes in general

$$\epsilon = nx + \frac{n^2 - n}{2}.y + \frac{n^3 - 3n^2 + 2n}{6}$$

If in this equation we substitute for x, y, and z, their respective values as given by Hallström's experiment: to wit, for x, the number 0.000102, for y, 0.000007 and for z, 0.000001; and make n successively equal to each term in the temperature series, viz: 1., 2., 3., etc. we should reproduce almost exactly

the successive values of t as given in the table. The last term would be a little in excess, viz: 0.001455 instead of 0.001446; but by considering x as only 0.0001, the difference would take the contrary sign.

It is however obvious *a priori*, that these values of x, y, and z, have not their proper relations; since the difference of the third order is already in the same decimal place with that of the second. It is farther likely that in such a course of experiment the extension would be read too high, from the extreme difficulty of controlling the temperature of the medium by which the heat is applied, so that it shall not pass its proper degree before the reading is made. Accordingly we need not be surprised to find, as is shewn in the table, this identical result the very highest (even exceeding that of iron-wire) nor its matriculating equation, when applied in terms to temperatures much more elevated but within the limits of observation, offering extensions far beyond the actual. In fact, at a temperature of 300° C. these values of the constants would accuse an extension more than twice as great as that carefully observed by Dulong and Petit.

The considerations which I have indicated, as implying in advance an inaccuracy in the constants derived from Hallström's experiments, do not affect the co-efficients, i. e. the ratio of combination. It seems to me, therefore, that we are warranted in using the equation, provided we assign suitable values to x, y, and z, and such as will accord in reasonable limits with the result of other experiments. Hence we may, if we please, by giving to t the actual values which it is found to have at different points of the scale from 0° to 300° C., obtain by successive eliminations, values of x, y, and z, which will correspond up to 300° C. with the ascertainment of t; but we have no guarantee of accuracy beyond that limit. I have therefore preferred to establish the constants by another method.

It is obvious, from the whole course of the practical results, that the value of the first term cannot be materially wrong; and therefore that the corrections need be applied only to y

and z. It is moreover easy to see that these ought to be functions of x, and of a similar order with their co-efficients respectively; so that they may be expressed thus:

$$y = mx^{\frac{m}{n}} \text{ and } z = \sqrt[n]{mx^{\frac{m}{n}}}^{m}$$

And if we consider that the phenomenon of extension is an affection of a general law of repulsion, by which the forces vary inversely as the squares of the molecular distances, we shall have, at any epoch, $m = 3$, and $n = 2$. Substituting these values, we have

$$y = 3x^{\frac{3}{2}} \text{ and } z = \sqrt[3]{3x^{\frac{3}{2}}}^{3}$$

And taking $x = 0.0001$ and translating the literal equations we have $y = 0.000001$

and $z = 0.000000005 +$

With these quantities, applied in the equation for the series before given, I have calculated a table of extensions up to 2000° C.; part of which will be given presently. They yield

$\epsilon = 0.0011356$, at 100° C.; a value not differing materially from 0.0011806, " as found by Dulong and Petit; and

$\epsilon = 0.0043253$, at 300° C.; while the same observers found it to be 0.0043858.

If the value of x had been left as at first, 0.000102, the accord would have been more striking; but as it is, it is satisfactory enough, and we may therefore consider the analytic law as sustained through the whole range of experiment.

Nor beyond this range are we left altogether without resources of control and verification. These are furnished, in the comparison of the successive extensions with the increments of specific heat, which have been signalized by the observers Dulong and Petit; the classicality of whose researches has given me occasion already so often to refer to them.

They found the specific heat of iron at varying temperatures (that of water being unity) as follows:*

* *Ann. de Chimie et Physique*, vii. 147.

Table shewing the specific heat of Iron corresponding to the temperatures inscribed.

temperature.	specific heat.
100.°	0.1098
200.	0.1150
300.	0.1218
350.	0.1255

In order to render this scale comparable at a higher temperature, it is necessary to convert the numbers in the column of specific heat into an empiric formula; which, expressing exactly the increments within the range of observation, may be supposed capable of a similar expression without serious error at higher temperatures.

If we call then, s, the specific heat of the metal between 0° and 100°, and m, any term in the arithmetical series of temperatures (progressing by hundreds of degrees, i. e. so that $m = \frac{t°}{100}$) and x', y', etc. the constants determined by experiment, we derive, from the law of the series,

$$ds = \overline{m-1} \,.\, x' + \overline{m-1} \,.\, \frac{\overline{m-2}}{2} \,.\, y';$$

and calling, s', the specific heat corresponding to a temperature above 100°,

$$s' = s + \overline{m-1} \,.\, x' + \overline{m-1} \,.\, \frac{\overline{m-2}}{2} \,.\, y'$$

From the first three terms of Dulong and Petit's experiment, have $x' = 0.0052$, and $y' = .0016$; values, which (although that of y' appears, from theoretical considerations like those suggested in treating the equation of extension, too high) I have not allowed myself to alter. It is with these numbers and the constant 0.1098, replacing s in the last equation, that I have calculated a table of specific heat corresponding to temperatures as high as 2000° C.

But, before presenting this table, I wish to offer another shewing the comparison just now indicated; which has been calculated by the first of the two equations just now given, viz:

Table shewing the ratio of the two scales of specific heat and extension.

temp.	ds.	ϵ	$\frac{\epsilon}{ds}$ = ratio.
100.°	0.0052	0.0011356	0.218
200.	.0120	.0025757	0.215
300.	.0204	.0043253	0.212
400.	.0304	.0063894	0.210
500.	.0420	.0087730	0.209
600.	.0552	.0114811	0.208
700.	.0700	.0145187	0.207
800.	.0864	.0178908	0.207
900.	.1044	.0216024	0.207
1000.	.1240	.0256585	0.207
1100.	.1452	.0300641	0.207
1200.	.1680	.0348242	0.207
1300.	.1924	.0399438	0.208
1400.	.2184	.0454279	0.208
1500.	.2460	.0512815	0.208

The numbers in the last column are so uniform, that we are almost warranted in saying that the two scales follow the same march. Indeed, after the first three or four terms, when the already signalized disproportionate value of y becomes absorbed in the progression of its co-efficient, their rate is sensibly the same. Nor is this delusive, by being appropriate only to the earlier terms of the temperature-series; for in extending the calculation, as I have done for verification up to 3000°, I find, at that term, a value for $\frac{\epsilon}{ds}$ of 0.21854, differing only in the fifth decimal place from that at the first term.

It is manifest, therefore, in regard to the increments of specific heat and those of extension, that whether or not we have obtained *the true law for either*, we have *the same law for both;* a condition, requisite in the general theory and here specially satisfied in the constant ratio which has been educed. It is not my purpose, however, to argue this point farther than merely to allude to the mutual confirmation afforded by the two series, and to indicate the verification which I before expected to procure for the first by a suitable comparison with the second.

I shall now present the two series in juxtaposition for the first 1700° C.; which includes all the range necessary for my present object.

Table shewing the extension of Iron, due to its specific heat at different temperatures, and also the actual extension at the same temperatures; in parts of original length, viz: unity at zero of the Centigrade thermometer.

temp.	s' specific heat.	η extension due to spec. heat.	ϵ actual extension.
100.°	0.1098	0.0011356	0.0011356
200.	.1150	.0023788	.0025757
300.	.1218	.0037791	.0043253
400.	.1302	.0053863	.0063894
500.	.1402	.0072501	.0087730
600.	.1518	.0094199	.0114811
700.	.1650	.0119455	.0145187
800.	.1798	.0148766	.0178908
900.	.1962	.0182627	.0216024
1000.	.2142	.0221535	.0256585
1100.	.2338	.0265987	.0300641
1200.	.2550	.0316479	.0348242
1300.	.2778	.0373507	.0399438
1400.	.3022	.0437568	.0454279
1500.	.3282	.0509158	.0512815
1600.	.3558	.0588774	.0575096
1700.	.3850	.0676913	.0641172

The aim that I had in constructing this table, which for illustration has been extended more than was otherwise absolutely necessary, and the uses to be made of it, are very plain. It is obvious that the accident of fusion of any substance (to give the subject its greatest generality) is limited: on the one hand, by what is termed the *specific heat* of the substance, i. e. its relative property of progressive proportionate expansion without change of form under successive increments of heat, or in other words its capacity of (if I may be allowed the word) accommodating such heat; and, on the other, by (what I shall call for greater distinctness and because, too, of the considera-

ble individual variations in its manifestation) the *phenomenon* of actual expansion. These two circumstances—the property and the phenomenon—are distinct affections; their qualifications are arrived at, as we may see, by quite independent modes of observation and methods of calculation; they are simply correlatives.

Now, it will be comprehended that if the specific heat of a substance remained constant at all temperatures—if there was no increasing adaptation for entertaining, and as it were absorbing among its own particles, the fresh increments of heat as they may be applied, the tendency of such applications (which would be accompanied, every one, by an exactly corresponding elevation of temperature) would be altogether to induce a *change of form* in the substance. And this tendency would become actual, and the change of form (which for a solid body is termed *fusion*, for a liquid, *vaporization*, and for gases has no name as yet, merely because our means of observation cannot appreciate its occurrence) take place, whenever the repulsive force of the sum of the heat-increments became equal to the molecular cohesion of the substance itself.

We have an illustration of this in the case of *water*. When heat is applied to this substance, it of course expands; but its specific heat varying at the same time so slightly that it may be regarded as constant, the effect of the heat applied is all in the direction of a change of form; and the cohesive force to resist this change being very small, the point is soon reached where (to use the greatest simplicity of phrase) the water cannot hold the heat and be *water*. It therefore becomes vapor.

If, in the other extreme, we assume the case of a substance whose specific heat, instead of being constant, is expressed by a series which, at an infinitely high temperature, becomes itself infinite; its capacity for accommodating heat and consequently its proportionate progressive expansibility are infinite likewise. Such a body is in the abstract incapable of *change of form*.

It follows that, in producing a change of form in any substance, it is necessary for the actual expansion, which is a

constant function of the cohesive force of the substance in question, to fall below the expansion due to the scale of specific heat, whose terms are functions of the repulsive force of heat. When this takes place, of course the cohesion of the substance is overcome; and its particles, whether of a previously solid, liquid, or even gaseous body, are left (if no more heat is applied) to obey the solicitations of their own gravitating forces compared with the gravity of other particles around them.

If all this be premised, the object and application of the table just now given is very simple. It is only requisite to see in its columns at what temperature the cohesive force has been overcome,—which is indicated by the equality of η and s,—to find the point where fusion commences. An inspection shews this to be between 1500° and 1600° C. i. e. 2732° and 2912° F.; a result which accords sufficiently near with those of observation, as already given, to warrant the non-existence of any material error in the data and elements of which use has been made.

In the present state of these data, it would be obviously premature to have given a greater minuteness to the terms of the table, in order to present with nearer precision the temperature of the point of fusion. Such precision, however, is readily procurable, without the trouble of tabulation, from the general equations which have served already, and which may be expected to continue to serve even when farther experiments have introduced modifications in the data. Indeed, I should have contented myself with merely giving the equations and converting them numerically so as to deduce at once the point in question, had I not supposed that additional clearness would otherwise be imparted to the expression of my views, and that some might have interest in tracing the progression of the agencies at work in producing fusion.

Recurring for a moment to these general equations, the first of them, viz:

$$s = nx + \frac{n^2 - n}{2} \cdot y + \frac{n^3 - 3n^2 + 2n}{6} \cdot z$$

becomes, in substituting the numerical values of x, y, and z, respectively,

$$s = \frac{11.8202\,n + 0.1797\,n^2 + 0.0001\,n^3}{120000};$$

and if we employ for n its value $\left(\frac{t}{10}\right)$ and increase the denomitor to millionths for the sake of avoiding so many decimal places to the right of zero, we shall find finally

$$s = \frac{118.202t + 0.1797t^2 + 0.00001t^3}{12000000}.$$

Such is the expression of the actual extension for any temperature, t being counted by single degrees.

To reduce the other to a similar expression, we have in the equation (equivalent to that for s', on p. 155)

$$s' = 0.1062 + 0.0028\,m + 0.0008\,m^2$$

the value of $m = \frac{t}{100}$. Substituting this term of t and converting as the former into a fractional form we have

$$s' = \frac{106.2 + 0.028t + 0.00008t^2}{1000}$$

to express the specific heat for any number of degrees (t) of temperature.

To deduce a formula for the extension (η) due to the increase of specific heat beyond 100°, the fraction 0.1098 representing the specific heat from zero up to that term, and 0.000011356 being the extension for each degree within that range, reckoned uniformly, we have

$$u = 0.000011356t$$

$$\text{and} \quad \eta = \frac{s'}{0.1098} \cdot u = \frac{0.000011356t}{0.1098} \cdot s'$$

Substituting the value of s', just now given, and effecting the multiplication, we deduce finally

$$\eta = \frac{\overset{ii}{0.0012060072t} + \overset{vi}{0.000000317968t^2} + \overset{ix}{0.000000000090848t^3}}{109.8}$$

for the extension corresponding to the repulsive force of heat for any temperature represented by t°.

By means of these two equations, of course the numerical value of t, suitable to the hypothesis of the equality of the two scales, can be educed. In fact, we only have to make $\varepsilon = \eta$; that is (giving the same number of places in the denominator of both expressions) in terms of t,

$$\frac{118.202t + 0.1797t^2 + 0.00001t^3}{12000000} = \frac{120.60072t + 0.0317968t^2 + 0.000098485t^3}{10980000}$$

Reducing the fractions, and dividing both sides by t, the equation becomes a simple quadratic, whose resolution has given me

$$t = 1523°.5$$

This temperature, corresponding to 2774°.3 Fahr., is then, agreeably to our premises, the temperature at which iron is ready to enter into fusion. It is curious to observe how near this independent calculation agrees with the experimental result of Mr. Daniell, which, as I have already mentioned, was 2786° Fahr. or 1530° Cent. for cast-iron in fusion.

This coincidence may be the result of accident; though I confess I do not so regard it myself: but lest any one, for want of full reflection and from the very accord, should be tempted to consider the issue of the calculation as an arbitrary one, I will go on to remark, that it is independent of any thing but the law of progression of the two series; which law, it has been shewn, is almost rigidly in accord with the numerical results of the best experiments. The actual expansion, for instance, for the first 100° C. (which, in the application of this law, happens to come out a little less than the observation of Dulong and Petit) is immaterial, in the comparison of the two scales, to the point of their convergence and the change of sign of their difference. This will be seen at once, in eliminating from both sides of the equation last given (which contains the respective values of η and ε) the factor 0.000011356, which is the extension I have assigned at 100° C.; so as to present the ratio $(\eta : \varepsilon)$ disconnected with this term. It is not necessary that I should go through this elementary transformation here.

At the same time it must be remarked, that if the problem

were to be solved by a strict comparison of *expansions*, i. e. of volumes, (which, had the data served, would have been more appropriate) the result would have varied, in presenting a lower temperature as the point of incipient fusion. This is accused, too, by the tabular comparison on page 156.

Such are the conclusions from the analogical method, to which I have had resort. There are besides other modes of investigation; which, were there data sufficient, could be employed to concur in, or correct, the result of this. So, for instance, a measure of the heat developed during rupture by extension, or an inference of the quantity of that heat from a comparison of the *contraction* which takes place at the point of rupture with the law of the increments of specific heat as here given (which would be an *inverse* method of resolution) would, either, be an indication of the temperature necessary for fusion. But, beyond the fact, the former particular has not as yet been ascertained at all; and the latter does not appear to have been measured with any precision. The mean of Mr. Telford's statements on this last point indicated for me a little over 1400° C.; but although he seems to have been aware of the interest which might attach to the circumstance,* he did not read nearer than the $\frac{1}{16}$ of an inch—a quantity obviously capable of inclosing a considerable range of temperature.

Finally, it will be seen that I have confined myself only to the consideration of the affection by heat of (so called) *wrought* iron: 1°. because the observations of the phenomena of crude-iron do not as yet afford basis enough for the view which I desired to take: 2°. because (what has been already alluded to,) the different specimens of refined-iron in the hands of different observers are much more likely to afford an uniform

* I quote the words of his note appended to the account of his experiments given to Prof. Barlow. "It is a curious fact and deserving the attention of philosophers, that frequently at the moment of rupture, the bar [of iron] acquires such a degree of heat in the fractured part as scarcely to enable [to allow] a person to hold it grasped in his hand without a painful sensation of burning." Barlow: *Strength of Materials*, p. 269. London, 1837.

result than can be anticipated for the indefinite variety of manufactured crude-iron: and 3°. because, I suppose, we are warranted in assigning a lower temperature for the fusion of crude than malleable iron, at least in the proportion of free carbon which such crude-iron may contain; and this, not only in that the presence of such carbon brings the substance under the general category of fusibility of multiple compounds, but also specially that the combination of the carbon with oxygen gives rise to products (which may be supposed, for indefinite intervals, as not escaping from the mass) having a lower specific heat than has been ascribed at high temperatures to iron, and therefore assisting in the developement of an increased sensible heat.

For all this and more, I presume that the determination of the point of fusion for malleable-iron prescribes also a limit to the fusibility of crude-iron; and, in conclusion, that what has been stated here in regard to the former, will serve in its place to disabuse us of the notion of such excessively high temperatures as have been assigned for the fusion of either; which was, as I said at first, my chief design in making this note.

NOTE D,

(referred to on page 75.)

On the Fusibility of different Compounds of Silica, Alumina, Lime and Magnesia.

THIS subject, so important in its social uses to metallurgy, and to the arts which furnish, for our daily purposes, manufactures of porcelain and pottery, has been experimentally examined by Achard, Berthier, Descotils and Lampadius. M. Berthier, in particular, has defined the limits within which silica is of useful application.

Nor is it of less importance to theoretical science, if its research and developement should lead to the exposition of clearer and more definite laws as to the modes and effects of heat; and thus impart a higher generalization, than we now possess, to the agencies (no doubt simple, could we discover them) which produce and govern all chemical action.

It was in both these aspects that I, also, came to make the experiments, the account of which occupies this note.

In the midst of a patient comparison of the results obtained by others, and principally those of M. Berthier, it became obvious that the data for the generalization I hoped for, could only be obtained by a more full and systematic experimentation than had yet been made; that, even upon full existing experiments, no verbal history or explanation could characterize, with sufficient precision, processes differing but slightly in the proportions of elements engaged and to be appreciated, not only from inspection of the actual visible product, but also from the behaviour (so to speak) of the elements while the process was going on; and that, therefore, to pursue the investigation properly, an original set of observations would have to be made. And these indications,—coupled with the reflection that it would be an irksome consumption of time, and thankless, (if even I had it, and the necessary means and implements at

disposal) merely to do over again what so distinguished and skilful a chemist as M. Berthier had already done,—guided me in the adoption of the method which I employed; and which was to expose proportionately small quantities of the substances in question to the action of an open flame, urged by a strong and uniform blast.

For this, I used a blow-pipe apparatus which I caused to be especially constructed; and which, as it presents conveniences and advantages not generally availed of, I allow myself in pausing a moment to describe. The apparatus is in fact a miniature blast-engine. A brass forcing pump, with a piston of 2 inches diameter and 7 inches stroke, was enclosed in a brass cylinder, serving as a regulator, 5 inches in diameter and 14 inches high; and provided with a suitable stuffing box to allow the piston-rod to work through. The whole was then set in the corner of a shelf under a table (made for another purpose not interfered with by the arrangement, except when in actual use;) and a brass tube, $\frac{3}{8}$ of an inch in diameter, was then screwed on to the side, near the top, of the regulator and conveyed the blast to a point equidistant from the ends, and two inches from the edge, of the table. At that point the table itself is pierced to allow a bent tuyère, having a full horizontal motion in revolution and capable of removal at pleasure, to pass down and work in the horizontal tube aforesaid. A nozzle of glass, (as I used) or of platinum, inserted in this tuyère, completes the arrangement at this extremity; while steel connecting rods and a treddle, fixed to the scroll foot of the table beneath, provide for giving convenient motion to the piston at the other.

The combustible employed was *wax*, cast in a tube of 1.25 inches diameter, around a wick composed of 40 strands of cotton; which I found to furnish flame enough for the purpose, and a heat surpassing what I have ever before seen generated with a blow-pipe. And, indeed, if one may judge from the results, the temperature was uniformly higher than that obtained by the large furnace of M. Berthier, which he employed for the more refractory of his experiments.

I had supposed at first, from the fact that in many cases (as

in the clay-pyrometer of Wedgewood, for instance) a low temperature for a long time produces as much effect as a higher temperature for a shorter time, that I would be able to measure approximately the degree of fusibility by the scale of *the times employed* in producing fusion: but practically this was not the case—the more fusible compounds melted instantly; and none required as long as 2 minutes. The infusible ones were not exposed longer than 10 minutes;—there being abundant evidence from their behaviour, that no closer combination was going to take place than had occurred in half that time.

As to the absolute temperature produced, it is rather difficult to establish that upon exact and satisfactory grounds; but nevertheless, the apparatus was arranged so as to admit the application of means for measuring the quantity and density of the air furnished and the weight of combustible consumed in a given time. Not to make too long digression here, I shall in another place and hereafter give the details and results of this topic.

The elements themselves were with great care exhibited in a state as nearly as possible approaching purity, and of course finely comminuted. And, as they were meant to be united in constant atomic proportions, it was obvious that much time would be spared, consistent with due accuracy, if a method of constant *volumes* were substituted for that of *weights*. Accordingly, having ascertained the absolute specific gravity of each, its combining volume was deduced from the system of atomic weights in which hydrogen is taken as unity; and the several volumes were then measured on a piece of glass tube of perfectly uniform bore, and the tube cut and ground down to the proper respective lengths. A thin glass plate was then cemented to the bottom of each; and a piece of light wire, wrapped round and projecting, formed a handle. It was easy, when the substances were taken up in these tubes, from the aspect of the mass completely visible on all sides, to judge and be assured of a uniformity of condensation in every case; and from the pains bestowed in this regard and the verification of weighings in instances taken indiscriminately, I am satisfied with the full accuracy of this part of the means employed.

And had it been less even, I am not less satisfied, from some experience in comparing weights (otherwise of good character) among themselves, that it would have equalled what could have been obtained from single weighings, with weights other than those carefully compared and corrected for one's own use.

The elements, being thus ascertained in proportion, were then intimately mixed in a mortar; and being poured out upon suitable papers, the portion for experiment was taken up on the recurved end of a piece of fine platinum wire, and exposed to the flame.

Although the product of the fusion, when it occurred, was thus small in quantity, and so did not allow, in such high degree as if the mass had been greater, estimation of the character of its *fracture*,—the proportionate surface exposed was so great as to exhibit, for the whole mass, every step in the process from mere coherence up to vitrification. And it was upon such indications, that the *comparative fusibility* will be found in many instances inserted in the Table.

Circumstances, out of my control, prevented my taking (as I otherwise meant) the specific gravity of each fused or partially fused product, and thus furnishing another datum, by whose comparison with the calculated specific gravity of each compound before fusion, an inference might be drawn as to the respective effect of the agencies at work.

In all the experiments, I had the assistance of Mr. P. T. Tyson; a singularly expert manipulator and skilful in the appreciation of mineral characters. Nearly every result was examined and its description verified upon the journal by both of us; so that, besides the value of his aid in other regards, it confers a double guarantee of the fidelity of the account given.

The following Table, which gives this account, is divided into seven columns; of which, the first contains the nomenclature of the compound, on the assumption (which the experiments seem to justify) that each more electro-negative element presents its oxides (though in different degrees of oxidation) as *acids* to the other. Thus, for the binary combinations, I have used the terms *silicates*, *aluminates* and *magnesiates:* for the ternary, the term *silicate of an aluminate* of magnesia or lime;

only, when the two more electro-positive bases were atomically equal, I have employed the phrase, equally intelligible and more symmetrical, (for instance,) *silicate of alumina and lime*, *di-aluminate of magnesia and lime:* and for the quaternary, a nomenclature founded on the same principles.

The second column contains the number of atoms of each element in the several compounds. As there is no danger of confusion, the elements are denoted by the initial letter of their English names; and I found it convenient, in disposing them symmetrically for experiment, to arrange the three metallic oxides in the alphabetical order of their initials.

The next four columns contain the parts of unity represented by the several elements in each mass; which I thought might be, with some readers, a convenient additional illustration of the subject, and which I took the pains to calculate proportionally upon the following combining weights: viz.

Silica: .	46.5	Lime: . .	28.5
Alumina: .	51.4	Magnesia: .	20.7

The last column, or more properly the opposite page, contains the characteristics of each result; ascribed according to a constant scale of fusibility, to which I rigidly adhered. Thus the aspect of the product may, in the descending series, be called *glass; enamel*—when the substance has run upon the wire; *enamelled*—when only the external parts of the mass run; *porcelain; porcellanized*—when the matter was not reduced in bulk so as to present an even surface; *porcellanoïd; agglutinated; strongly coherent; coherent; slightly coherent;* or *pulverulent.*

The form, likewise in a descending order of fusibility, may be a *bead*—whose section contains not less than 240°; a *button*—any thing less than 240° down to a flattened oval; or a *mass.* A *frit* is a scoriform mass.

And the texture of all specimens having a lower than porcellanized aspect may be either such as to *break* between the nails; or to *crush* between the nail and iron; between the nail and polished mahogany; between the nail and the skin of the fingers; between the fingers.

With these characteristics, it seemed to me that a sufficiently approximate scale of comparative fusibility had been employed.

Besides these indications, reference has also been made to any remarkable physical developement, occurring during the experiment; as, for instance, a more than ordinarily intense luminousness, an unusual enlargement or contraction in bulk, etc.—circumstances proper to be recorded, although we may not yet be able to derive any precise explanation of the causes or mode of their origin or effect.

In some cases, where the proportions experimented on happened to be the same (exactly or very nearly) with those already recorded by other observers, I have inserted likewise the character of their result.

As to the arrangements of the Table in other regards, I have endeavoured to make them so palpable as not to need any long verbal explanation.

The number of substances employed, of course, limited the orders of combination; and the number of atoms, the permutations in each order. Only in the quaternary series, which is manifestly capable of great extension, I confined myself to such as I supposed were sufficient to exemplify the theory.

The other series are classified according to the atomic proportion of the element, presumed to present itself as an *acid;* and in these classes, the order of sequence of the binary combinations is dictated by the numerical scale of the said acid. A symmetrical arrangement of atoms governs in the ternary combinations; and in the quaternary series, the sequence is founded upon the increasing proportion of the most permanent alkaline base—the lime. Neither of these orders is entirely the same as that in which the experiments were performed; from whence it arises that in the results, references are made sometimes to preceding, sometimes to subsequent, compounds.

I have only to remark further in regard to this matter of sequence, that the word, *preceding*, always refers to all the previous results of the class in which it occurs, while the word, *last*, means the single immediately-preceding experiment.

I now present the Table referred to.

Results of Experiments on the Fusibility of

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Binary Combinations.					
Silica and Alumina.					
trisilicate of alumina,	S′ A‴	0.232	0.768	. .	. .
disilicate do.	S′ A″	0.311	0.689	. .	. .
trihemisilicate do.	S″ A‴	0.376	0.624	. .	. .
silicate do.	S′ A′	0.475	0.525	. .	. .
sesquisilicate do.	S‴A″	0.576	0.424	. .	. .
bisilicate do.	S″ A′	0.644	0.356	. .	. .
tersilicate do.	S‴A′	0.731	0.269	. .	. .
Silica and Lime.					
trisilicate of lime,	S′ L‴	0.352	. .	0.648	. .
disilicate do.	S′ L″	0.449	. .	0.551	. .
trihemisilicate do.	S″ L‴	0.521	. .	0.479	. .
silicate do.	S′ L′	0.620	. .	0.380	. .
sesquisilicate do.	S‴L″	0.710	. .	0.290	. .
bisilicate do.	S″ L′	0.765	. .	0.235	. .
tersilicate do.	S‴L′	0.830	. .	0.170	. .
Silica and Magnesia.					
trisilicate of magnesia,	S′ M‴	0.428	. .	. .	0.572
disilicate do.	S′ M″	0.529	. .	. .	0.471
trihemisilicate do.	S″ M‴	0.600	. .	. .	0.400
silicate do.	S′ M′	0.692	. .	. .	0.308
sesquisilicate do.	S‴M″	0.771	. .	. .	0.229
bisilicate do.	S″ M′	0.818	. .	. .	0.182
tersilicate do.	S‴M′	0.871	. .	. .	0.129

REMARKS.

slightly coherent.
do. do. in a somewhat higher degree than the preceding.
coherent; but less so than the bisilicate.
slightly coherent; rather less than the disilicate. B.; merely agglomerated.
coherent; less than the tersilicate.
do. the most so of any. Berthier found this strongly agglomerated.
do. less than the trihemisilicate.

frit; crushing between the fingers. B.; part scoriform, part pulverulent.
semi-fused; but not into a button.
fused into a button. Berthier do. 2½ hours heat of 175° P.
do. an enamel-button. Berthier found it to resemble porcelain.
do. an irregular enamel.
do. an irregular enamelled mass.
porcellanized.

slightly coherent; crushes rather less fine than the disilicate.
do. do. crushes rather less than the silicate.
more do. than the preceding. B.; softened but not fused.
strongly coherent; crushes entirely between the finger. B.; commt. of fusion.
do. do. crushes more fine than the tersilicate.
do. do. crushes more fine than the trihemisilicate.
do. do. crushes less fine than the last.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Binary Combinations.					
Alumina and Lime.					
trialuminate of lime,	A′ L‴	. .	0.375	0.625	. .
dialuminate do.	A′ L″	. .	0.474	0.526	. .
trihemialuminate do.	A″ L‴	. .	0.546	0.454	. .
aluminate do.	A′ L′	. .	0.643	0.357	. .
sesquialuminate do.	A‴L″	. .	0.730	0.270	. .
bialuminate do.	A″ L′	. .	0.783	0.217	. .
teraluminate do.	A‴L′	. .	0.844	0.156	. .
Alumina and Magnesia.					
trialuminate of magnesia,	A′ M‴	. .	0.453	. .	0.547
dialuminate do.	A′ M″	. .	0.554	. .	0.446
trihemialuminate do.	A″ M‴	. .	0.623	. .	0.377
aluminate do.	A′ M′	. .	0.713	. .	0.287
sesquialuminate do.	A‴M″	. .	0.788	. .	0.212
bialuminate do.	A″ M′	. .	0.832	. .	0.168
teraluminate do.	A‴M′	. .	0.882	. .	0.118
Lime and Magnesia.					
trimagnesiate of lime,	M′ L‴	. .	. .	0.805	0.195
dimagnesiate do.	M′ L″	. .	. .	0.734	0.266
trihemimagnesiate do.	M″ L‴	. .	. .	0.674	0.326
magnesiate do.	M′ L′	. .	. .	0.579	0.421
sesquimagnesiate do.	M‴L″	. .	. .	0.479	0.521
bimagnesiate do.	M″ L′	. .	. .	0.408	0.592
termagnesiate do.	M‴L′	. .	. .	0.315	0.685

REMARKS.

porcellanoïd.
porcellanized.
fused into an irregular mamelonated mass: less frit than the bialuminate.
do. a greenish enamelled button.
do. a button.
do. an irregular mass—partly a frit.
do. a bead.

no apparent action: mass crushes to powder in the fingers.
mass crushes to powder: less combination than in the silicate.
no apparent action.
slight combination but no fusion; mass remarkably luminous.
evidences of slight combination.
no apparent action.
slight combination.

crushes to powder in the fingers.
do. do.
do. do.
agglutinated; crushes in the fingers.
crushes to powder.
crushes to powder; less affected than the magnesiate.
do. do.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Ternary Combinations.					
Silica, Alumina, Lime.					
Silicate of					
alumina & lime,	S′ A′ L′	0.368	0.407	0.225	. .
dialuminate of lime,	S′ A′ L″	0.300	0.332	0.368	. .
trialuminate do.	S′ A′ L‴	0.254	0.280	0.466	. .
bialuminate do.	S′ A″ L′	0.262	0.578	0.160	. .
Disilicate of alumina & lime,	S′ A″ L″	0.226	0.498	0.276	. .
trihemialuminate of lime,	S′ A″ L‴	0.198	0.438	0.364	. .
teraluminate do.	S′ A‴L′	0.203	0.673	0.124	. .
sesquialuminate do.	S′ A‴L″	0.181	0.598	0.221	. .
Trisilicate of alumina & lime,	S′ A‴L‴	0.162	0.539	0.299	. .
Bisilicate of					
alumina & lime,	S″ A′ L′	0.538	0.297	0.165	. .
dialuminate of lime,	S″ A′ L″	0.462	0.255	0.283	. .
trialuminate do.	S″ A′ L‴	0.404	0.224	0.372	. .
bialuminate do.	S″ A″ L′	0.415	0.458	0.127	. .
trihemialuminate do.	S″ A″ L‴	0.331	0.365	0.304	. .
teraluminate do.	S″ A‴L′	0.337	0.559	0.104	. .
sesquialuminate do.	S″ A‴L″	0.306	0.507	0.187	. .
Trihemisilic. of alum. & lime,	S″ A‴L‴	0.280	0.463	0.257	. .
Tersilicate of					
alumina & lime,	S‴A′ L′	0.636	0.234	0.130	. .
dialuminate of lime,	S‴A′ L″	0.563	0.207	0.230	. .
trialuminate do.	S‴A′ L‴	0.505	0.186	0.309	. .
bialuminate do.	S‴A″ L′	0.516	0.380	0.105	. .
Sesquisilicate alum. & lime,	S‴A″ L″	0.466	0.344	0.190	. .
trihemialuminate of lime,	S‴A″ L‴	0.425	0.314	0.261	. .
teraluminate do.	S‴A‴L′	0.433	0.479	0.088	. .
sesquialuminate do.	S‴A‴L″	0.398	0.440	0.162	. .

REMARKS.

fused into a transparent glass bead.
do. a mamelonated button.
porcellanized. M. Berthier found, a mass partly pulverulent.
fused into a glass bead; more fusible than the preceding.
do. a glass button.
do. two buttons; less fusible than the last.
do. a button; rather more fusible than the last.
do. an irregular enamelled porcelain.
do. do. ; rather less fusible than the last. Lampadius found these proportions nearly, a porcelain.

fused into a transparent glass bead; more beautiful than S′A′L′.
do. do. do.
do. a glass button. Berthier, an opaque, porcelain-white button.
do. do. ; not so transparent as S″A′L′ or S″A′L″.
do. do. ; more enamelled and less transparent than last.
do. do. ; less enamelled and more transparent than last.
do. a transparent glass button. Lampadius, a porcelain.
do. a glass button; less transparent than the last.

porcellanized.
fused into a glass button.
do. a transparent glass button. Lampadius, a porcelain.
highly enamelled porcelain.
do. do.
do. do. ; less fusible than the last. *Epidote*. B.; compact button of granulated fracture.
enamelled porcelain.
do. do. ; not so fusible as the last.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Ternary Combinations.					
Silica, Alumina, Magnesia.					
Silicate of					
alumina & magnesia,	S′ A′ M′	0.392	0.433	. .	0.175
dialuminate of magnesia,	S′ A′ M″	0.334	0.367	. .	0.297
trialuminate do.	S′ A′ M‴	0.291	0.321	. .	0.388
bialuminate do.	S′ A″ M′	0.273	0.605	. .	0.122
Disilicate of alum. & magnes.	S′ A″ M″	0.244	0.539	. .	0.217
trihemialuminate of magnes.	S′ A″ M‴	0.220	0.486	. .	0.294
teraluminate do.	S′ A‴M′	0.210	0.696	. .	0.094
sesquialuminate do.	S′ A‴M″	0.192	0.637	. .	0.171
Trisilicate of alum. & magnes.	S′ A‴M‴	0.177	0.587	. .	0.236
Bisilicate of					
alumina & magnesia,	S″ A′ M′	0.563	0.311	. .	0.126
dialuminate of magnesia,	S″ A′ M″	0.500	0.277	. .	0.223
trialuminate do.	S″ A′ M‴	0.450	0.249	. .	0.301
bialuminate do.	S″ A″ M′	0.429	0.475	. .	0.096
trihemialuminate do.	S″ A″ M‴	0.361	0.398	. .	0.241
teraluminate do.	S″ A‴M′	0.347	0.576	. .	0.077
sesquialuminate do.	S″ A‴M″	0.322	0.534	. .	0.144
Trihemisilic of alum. & magn.	S″ A‴M‴	0.301	0.498	. .	0.201
Tersilicate of					
alumina & magnesia,	S‴A′ M′	0.659	0.243	. .	0.098
dialuminate of magnesia,	S‴A′ M″	0.601	0.221	. .	0.178
trialuminate do.	S‴A′ M‴	0.551	0.203	. .	0.246
bialuminate do.	S‴A″ M′	0.530	0.391	. .	0.079
Sesquisilicate of alum. & mag.	S‴A″ M″	0.492	0.362	. .	0.146
trihemialuminate of magn.	S‴A″ M‴	0.458	0.338	. .	0.204
teraluminate do.	S‴A‴M′	0.444	0.490	. .	0.066
sesquialuminate do.	S‴A‴M″	0.416	0.461	. .	0.123

REMARKS.

slightly coherent.
strongly coherent; not crushed in the fingers.
incipient porcellanization.
strongly coherent; only crushed between the nail and a steel anvil.
do. do. ; breaks, but does not crush, do. do.
porcellanized, mamelonated.
strongly coherent; contracts in bulk, very much.
enamelled; does not break under the nail.
porcellanoïd.

slightly coherent.
porcellanized.
do.
strongly coherent.
porcellanized.
porcellanoïd.
porcellanized.
do.

porcellanoïd; breaks with the nail.
do.
do.
do.
strongly agglutinated.
porcellanized.
porcellanoïd; more tender than S‴A′M‴.
do. ; less tender than the last.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Ternary Combinations.					
Silica, Magnesia and Lime.					
Silicate of					
magnesia & lime,	S′ L′ M′ 0.486	. .		0.298	0.216
bimagnesiate of lime,	S′ L′ M″ 0.399	. .		0.245	0.356
termagnesiate do.	S′ L′ M‴ 0.339	. .		0.208	0.453
dimagnesiate do.	S′ L″ M′ 0.374	. .		0.459	0.167
Disilicate of magn. & lime,	S′ L″ M″ 0.321	. .		0.393	0.286
sesquimagnesiate of lime,	S′ L″ M‴ 0.281	. .		0.344	0.375
trimagnesiate do.	S′ L‴M′ 0.304	. .		0.560	0.136
trihemimagnesiate do.	S′ L‴M″ 0.268	. .		0.493	0.239
Trisilicate of magn. & lime,	S′ L‴M‴ 0.240	. .		0.440	0.320
Bisilicate of					
magnesia & lime,	S″ L′ M′ 0.654	. .		0.200	0.146
bimagnesiate of lime,	S″ L′ M″ 0.571	. .		0.175	0.254
termagnesiate do.	S″ L′ M‴ 0.507	. .		0.155	0.338
dimagnesiate do.	S″ L″ M′ 0.545	. .		0.334	0.121
sesquimagnesiate do.	S″ L″ M‴ 0.438	. .		0.269	0.293
trimagnesiate do.	S″ L‴M′ 0.467	. .		0.429	0.104
trihemimagnesiate do.	S″ L‴M″ 0.423	. .		0.389	0.188
Trihemisilic. of magn. & lime,	S″ L‴M‴ 0.387	. .		0.355	0.258
Tersilicate of					
magnesia & lime,	S‴L′ M′ 0.739	. .		0.151	0.110
bimagnesiate of lime,	S‴L′ M″ 0.666	. .		0.136	0.198
termagnesiate do.	S‴L′ M‴ 0.606	. .		0.124	0.270
dimagnesiate do.	S‴L″ M′ 0.642	. .		0.263	0.095
Sesquisilic. of magn. & lime,	S‴L″ M″ 0.586	. .		0.240	0.174
sesquimagnesiate of lime,	S‴L″ M‴ 0.540	. .		0.220	0.240
trimagnesiate do.	S‴L‴M′ 0.568	. .		0.348	0.084
trihemimagnesiate do.	S‴L‴M″ 0.524	. .		0.321	0.155

REMARKS.

fused into a translucent enamel bead.
do. do. do. ; more translucent than the last.
enamel mass.
porcelain; unenamelled.
porcellanized.
do.
porcellanoïd; crushes between the nail and finger.
only agglutinated; crushes between the fingers.
less agglutinated than the last.

opaque enamel bead.
translucent enamel button. Pyroxene. B. found a compact translucent mass.
enamel button; more translucent than the last.
enamel bead; more opaque than S″L′M′. Pyroxene. B.; opaque compact vitreous enamel button. [button.
highly enamelled porcelain.
porcelain; more highly enamelled than the last.
enamel button. Peridote. Berthier found it a compact button.

porcelain; slightly enamelled.
do. ; more enamelled than the last.
do. ; highly enamelled.
beautiful enamel bead.
enamel button; not so fusible as the last.
do. ; more fusible than the last.
do. ; porcellanous in the centre.
do. ; more fused than the last.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Ternary Combinations.					
Alumina, Magnesia and Lime.					
Aluminate of					
magnesia & lime,	A′ L′ M′ . .	0.511	0.283	0.206	
bimagnesiate of lime,	A′ L′ M″ . .	0.424	0.235	0.341	
termagnesiate do.	A′ L′ M‴ . .	0.362	0.201	0.437	
dimagnesiate do.	A′ L″ M′ . .	0.398	0.442	0.160	
Dialuminate of magn. & lime,	A′ L″ M″ . .	0.343	0.381	0.276	
sesquimagnesiate of lime,	A′ L″ M‴ . .	0.302	0.334	0.364	
trimagnesiate do.	A′ L‴ M′ . .	0.326	0.543	0.131	
trihemimagnesiate do.	A′ L‴ M″ . .	0.288	0.480	0.232	
Trialuminate of magn. & lime,	A′ L‴ M‴ . .	0.258	0.430	0.312	
Bisaluminate of					
magnesia & lime,	A″ L′ M′ . .	0.676	0.188	0.136	
bimagnesiate of lime,	A″ L′ M″ . .	0.595	0.165	0.240	
termagnesiate do.	A″ L′ M‴ . .	0.532	0.147	0.321	
dimagnesiate do.	A″ L″ M′ . .	0.569	0.316	0.115	
sesquimagnesiate do.	A″ L″ M‴ . .	0.463	0.257	0.280	
trimagnesiate do.	A″ L‴ M′ . .	0.492	0.409	0.099	
trihemimagnesiate do.	A″ L‴ M″ . .	0.448	0.372	0.180	
Trihemialumi. of mag. & lime,	A″ L‴ M‴ . .	0.411	0.341	0.248	
Teraluminate of					
magnesia & lime,	A‴ L′ M′ . .	0.758	0.140	0.102	
bimagnesiate of lime,	A‴ L′ M″ . .	0.689	0.127	0.184	
termagnesiate do.	A‴ L″ M‴ . .	0.631	0.116	0.253	
dimagnesiate do.	A‴ L″ M′ . .	0.666	0.245	0.089	
Sesquialum. of magn. & lime,	A‴ L″ M″ . .	0.611	0.225	0.164	
sesquimagnesiate of lime,	A‴ L″ M‴ . .	0.565	0.208	0.227	
trimagnesiate do.	A‴ L‴ M′ . .	0.593	0.328	0.079	
trihemimagnesiate do.	A‴ L‴ M″ . .	0.549	0.304	0.147	

fused into an irregular, enamelled mass.
do. enamelled button.
do. enamelled mass.
porcelain; enamelled on the points and edges.
do. ; more enamelled than the last.
do. ; highly enamelled.
porcellanized; with minute out-sticking points.
do. ; more uniform surface than the last.
do. ; more enamelled than the last.

fused into a vitreous enamel button.
enamel button.
do. ; more lustrous than the last. Achard, nearly this proportion, a porcelain.
irregular enamelled mass.
enamel button. Achard, nearly this proportion, a porous porcelain.
enamelled porcelain.
do. ; more enamelled than the last.
do. ; do. do.

enamel button.
vitreous bead.
enamel button; more opaque than A‴L′M′.
do. ; more translucent than the three preceding.
do. ; less translucent, more lustrous than the last.
do. ; high lustre.
vitreous enamelled mass.
enamel button; less translucent than the last. The first six of these tersilicates were with difficulty retained on the wire, owing to their disposition to fly off at the instant of fusion.

NOMENCLATURE OF COMPOUND.	ATOMS.	COMPOUNDS BY WEIGHT.			
		SILICA.	ALUMINA.	LIME.	MAGNESIA
Quaternary Combinations.					
Tersilicate of the teraluminate of magn. & lime,	S‴A‴L′ M′	0.407	0.450	0.083	0.060
Bisilicate of the teraluminate of magn. & lime,	S″ A‴L′ M′	0.314	0.520	0.096	0.070
Tersilicate of the bisaluminate of magn. & lime,	S‴A″ L′ M′	0.478	0.353	0.098	0.071
Silicate of the teraluminate of magnesia & lime,	S′ A‴L′ M′	0.186	0.617	0.114	0.083
Bisilicate of the bisaluminate of magn. & lime,	S″ A″ L′ M′	0.380	0.420	0.116	0.084
Tersilicate of the aluminate of magnesia & lime,	S‴A′ L′ M′	0.581	0.214	0.119	0.086
Silicate of the bisaluminate of magnesia & lime,	S′ A″ L′ M′	0.234	0.518	0.144	0.104
Tersilicate of the sesquialuminate of magn. & lime,	S‴A‴L″ M″	0.356	0.393	0.145	0.106
Bisilicate of the aluminate of magnesia & lime,	S″ A′ L′ M′	0.480	0.266	0.147	0.107
Silicate of the aluminate of magnesia & lime,	S′ A′ L′ M′	0.316	0.349	0.194	0.141
Bisilicate of the trihemialuminate of magn. & lime,	S″ A″ L‴M‴	0.271	0.299	0.249	0.181
Silicate of the dialuminate of magnesia & lime,	S′ A′ L″ M″	0.211	0.290	0.262	0.237
Silicate of the trialuminate of magnesia & lime,	S′ A′ L‴M‴	0.190	0.209	0.348	0.253

REMARKS.

enamelled mass; semi-vitreous lustre.

enamelled porcelain.

vitreous bead; less transparent than S‴A‴L′M″.

do. ; not quite so transparent as S′A″L′M′.

do. ; do do. nor so thoroughly comb'd as S′A′L′M′.

do. ; more transparent than S‴A″L′M′.

do. ; do. than any of this series.

do. ; not quite so transparent as S″A″L‴M‴.

do. ; do. do. S′A‴L′M′.

do. ; more transpt. & more thoroughly combin'd than S″A″L′M′.

do. ; do. and more combined than S′A′L′M′.

fused into an irregular mass; part vitrified, part enamel, part porcelain.

porcelain slightly enamelled.

Such are the results of the experiments. Nearly every series goes to shew, that the limits of favorable combination exist in the proportions which have been employed; and that within these limits there is a yet narrower range, wherein the effect of the applied heat is a maximum.

The general deductions, which occurred to me as defining and substantiating this maximum, may be considered in two main aspects: both of which, however resting upon apparently different physical data, are, I doubt not, reciprocal, and flow from the same universal principle; although I confess myself not yet prepared, either to demonstrate satisfactorily the connection, or to establish in an unobjectionable manner the principle.

The first of these aspects is the one under which M. Berthier seems already to have regarded the subject; and which I have alluded to in speaking of the motives for the nomenclature. It is simply the presence, in different degrees, of the electro-negative element—oxygen—according to the proportions of the compound. All the experiments tended to shew, that much depended upon the degree of comminution and intimacy of mixture to which the substances were brought, i. e. to the contiguity of the elements: although inert at ordinary temperatures, it was manifest that the chemical combination took place when a temperature, suitable to the exercise of the actual affinities, was created, and that such combination always preceded fusion; and it would seem thence neither forced nor far-fetched to suppose, that the activity or intensity of those affinities are displayed in proportion either to the *oxidability*, or to the state of *oxidation*, of the substances respectively and of the mass.

The former of these conditions takes in account the combining weights of the oxidable elements; and rests only on the supposing that the mass shall be brought to the same isomerism, or chemical form, with the most oxidable of its constituents. Thus, for instance, we have in the substances in question degrees of oxidability of the original element from simple oxides up to ter-oxides,—or expressible under the forms RO, R^2O^3, RO^3: in a case of combination wherein the sesqui-oxide

the highest degree, all the elements must be brought to the state of sesquioxide; and of the teroxide, if that be the highest, and so on.

To give the hypothesis at once a sufficiently general expression: if we take any number of uncompounded elements, whose combining weights are represented by the symbols σ, α, λ, μ, etc. and the ratios of whose combination with oxygen are in any series, as RO, $RO^1 \ldots . RO^z$; n being the number of terms in such series; and if we take farther

$$\sigma = m\mu, \alpha = p\mu, \lambda = q\mu \ldots \text{etc.}$$

and ω the combining weight of oxygen; the formula of the assumed combination will be

$$m\mu + p\mu + q\mu + \mu + nx\omega = 1.$$

hence $$\mu = \frac{1 - nx\omega}{(m + p + q + 1)} = y; \text{ and}$$

$$\lambda = qy, \quad \alpha = py, \quad \sigma = my.$$

This equation, suitably applied according to the orders of combination, i. e. *binary*, *ternary*, etc. gave me quantities, with which the results of the Table (so far as the aluminates of magnesia and lime are not concerned) strikingly accord.

The consideration of the other condition which I just now mentioned, i. e. the state of *oxidation* of the substances compounded, gives rise to other expressions, whose exposition may assist in throwing light upon the subject.

If we call the radical in the different oxides *unity*, their respective proportions of oxygen are as under:

Silica: . . .	$1.067 = O^{\Sigma}$
Alumina: . . .	$0.875 = O^{\Delta}$
Magnesia: . . .	$0.630 = O^{M}$
Lime: . . .	$0.390 = O^{L}$

Now, this series represents experimentally the order of the respective efficiency of the substances in question, in combination at high temperatures; and hence we may regard the proportion of oxygen as the index of combination and of fusion.

Farther, it is demonstrable that the greatest amount of free oxygen exists when substances, having it in different degrees, are so presented to one another as to contain, each, equal quantities. Upon this it may follow, that the substances will be in the most favorable proportions for fusion, when they are in the ratios of the *mean* amount of oxygen to the amount held by each respectively.

These proportions are obtainable by the developement of equations like the following: in which n represents the order of combination; S, L, . . . etc. the combining weights of the oxides; and x, x', . . . etc. the proportional weight sought:

$$\frac{O^s + O^l + O^x + \ldots}{n} = z \qquad \text{and}$$

$$x = \frac{SO^s}{z}, \; x' = \frac{LO^l}{z}, \; \ldots \text{ etc.}$$

I have applied these equations to the series of combinations; with results generally approaching those given by experiment. Thus, for instance, the most fusible proportions are

by theory:	Silica:	0.675	by experiment:	0.644
	Alumina:	0.325		0.356
	Alumina:	0.803		0.844
	Lime:	0.197		0.156
	Alumina:	0.678		0.689
	Magnesia:	0.178		0.184
	Lime:	0.144		0.127

The general conclusion both from the theory and the experiments may be stated, as being that the most favorable proportions, in a binary combination, are the bisilicate of alumina and simple silicates of magnesia or lime, the teraluminate of magnesia or lime, and the simple magnesiate of lime. In cases of ternary combination the affinities seem to be exercised in a similar manner: thus, the most favorable proportions are the bisilicate of alumina and lime, or of magnesia and lime, the bisilicate of the sesquialuminate of magnesia, and the teraluminate

of the bimagnesiate of lime. If a quaternary combination be made, by replacing in the last named compound one atom of alumina by one atom of silica, the fusibility and beauty of the product is greatly increased.

The effect of very minute proportions of an additional element is shewn by comparing No. 13 of the silicates of alumina and magnesia (p. 176) with No. 1 of the quaternary series; wherein, an addition of less than 8 per centum of the most infusible substance raises the fusibility, from *strong coherence* to the state of *enamel*.

The other main aspect to which I have referred, is that which takes into account the relative *specific heats* of the substances presented for combination. Fully to develope and substantiate this aspect requires (in order to avoid being led away by coincidences merely accidental) a more comprehensive series of experiments than only upon the few substances mentioned here; and even to present all the details of the investigation in which I have occupied myself in regard to these few, would demand more space than can be allowed to this note. I can therefore do no more, here, than indicate the general steps which I have so far taken in the research; without meaning to affirm that some of these may not have hereafter, upon a larger experience, to be retraced.

The starting principle is the assumption that each ultimate atom of all elementary bodies has the same specific heat; a presumption, which the researches of Dulong and Petit long ago warranted, which later apparent anomalies induced chemists to call in question, but which I consider the recent labors of M. Regnault* to have confirmed. This principle is but announced in other language, when it is said, that the different combining weights of the various elementary bodies give rise to a manifestation of different affections by heat, or that the product of such combining weights by the respective specific heat is a constant quantity.

Nor does this constancy of product appear limited to the

* Comptes Rendus: xii. 56, *ss*.

so-called elementary bodies; but extends itself, duly modified, (or I should rather say, classified) likewise to compound bodies. Thus, it may be deduced from M. Regnault's observations (not to cumber ourselves here with the more complicated compounds, which have also been the subjects of experiment) that in the different oxides there exists a scale of *constants*, which may be expressed (if confined to whole numbers) as under

Scale of oxidation: .	RO,	RO^2,	RO^3,	R^2O^3	etc.
Scale of constants: .	5	7	9	13	etc.

Hence arises another position, viz: that the specific heat of oxidated radicals may be deduced from the ratio of their combining weights to their respective constants. In fact, the specific heat of the four substances concerned in this note may be stated thus:

Silica:	0.1935	calculated .	0.19132	experiment.	
*Alumina:	0.2529	do. .	0.21732	do.	(*sapphire*)
Magnesia:	0.2415	do. .	0.24394	do.	
*Lime:	0.1754				

The remaining assumptions are 1°. that the energy of combination follows the scale of constants, and 2°. that the tendency to fusion is a rational function of the specific heats; in other words, the fusibility of any compound of given substances having different specific heats is at its maximum, when the proportions are such as render the specific heat of the aggregate the least possible.

How these conditions have been satisfied, and the problem partially solved, will appear best by the simple exposure of the formula I employed: and to which I give here its most general expression.

Calling s, a, l, m, ... etc. the combining weights of any number of substances given to be compounded; and

$c + c' + c'' + c''' + \ldots . = C$, the several constants

* It is not to be expected that pure alumina deposited in fine powder, and nearly pure alumina in a crystal of sapphire, should manifest the same specific heat. As for that of lime, M. Regnault has not reported his experiments. Other observers have given various results from 0.2168 up to 0.300. Both cannot be right; and it is likely, neither.

and their sum, according to the chemical class to which they may belong; and

$h + h' + h'' + h''' + \ldots . = H$, the respective specific heats, so as that $h = \frac{c}{s}$, $h' = \frac{c'}{a}$, etc. and

S, A, L, M, ... the required proportions of each, so that H may be a minimum, n being the number of substances combined in any case: we have

$$S = \frac{cH}{Chn}$$

$$A = \frac{c'H}{Ch'n}$$

$$L = \frac{c''H}{Ch''n}$$

$$M = \frac{c'''H}{Ch'''n} \quad \ldots . \text{ etc. etc.}$$

If we take $n = 4$, and substitute for the other symbols their numerical value (c'' in this case being equal to c''') we shall derive for a quaternary combination, $S = 0.314$, $A = 0.317$, $L = 0.191$, $M = 0.140$.

This compound (which represents very nearly a composition by single atoms) I find noted on my journal, as fusing more instantly and developing more intense light than any other of the same series, although the vitreous bead produced was not so transparent as one or two others.

Such are the details which appeared to me fitting to be given at present in connection with the subject of this note. Elsewhere, I shall pursue the same matter again.

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